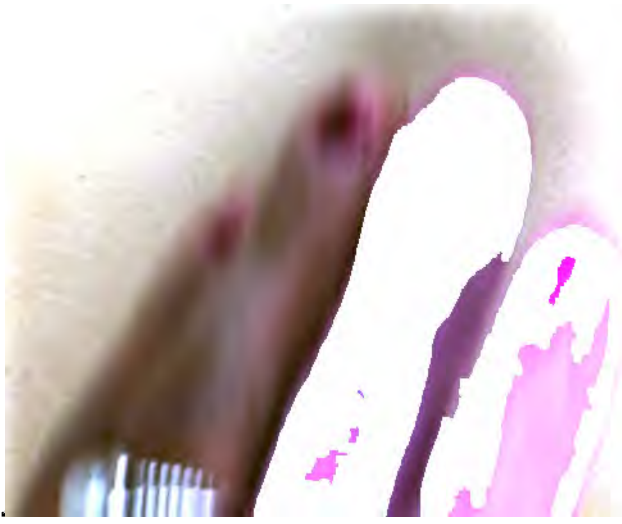
[illegible] Alice H. [illegible]



AN

ELEMENTARY COURSE

OF

NATURAL AND EXPERIMENTAL

PHILOSOPHY,

FOR THE USE OF HIGH SCHOOLS AND ACADEMIES,

IN WHICH

THE PRINCIPLES OF THE PHYSICAL SCIENCES ARE FAMILIARLY
EXPLAINED AND ILLUSTRATED BY NUMEROUS
EXPERIMENTS AND DIAGRAMS.

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Gift of Alice H. Bumstead, Sept. 1.

LIST OF CHEMICALS AND APPARATUS ADAPTED TO THE EXPERIMENTS CONTAINED IN THIS TREATISE.

List of Chemicals.

Acid, Arsenious.
  " Hydrochloric.
  " Nitric.
  " Oxalic.
  " Sulphuric.
  " Tartaric.
Alum.
Ammonia, Liquid, concentrated.
  " Carbonate.
  " Hydrochlorate.
  " Oxalate.
Antimony, Metallic.
  " Sulphuret.
Barium, Chloride.
Baryta, Nitrate.
Camphor.
Clay, Pipe, for luting.
Copper Leaf.
  " Nitrate.
  " Sulphate.
Distilled Water.
Gold Leaf.
Iodine.
Iron, Sulphate.
  " Sulphuret.
Lead, Acetate.
  " Oxide, Litharge.
Lime, Hydrochlorate.
Litmus.
Magnesia, Sulphate.
Manganese, Black Oxide, in powder.
Mercury.
  " Chloride, (corrosive sublimate.
  " Nitrate.
Phosphorus.
Platinum, Wire and Sheet.
Potassa, fused in pipes.
  " Carbonate.
  " Chlorate.
  " Bichromate.
  " Nitrate.
  " Prussiate.
Potassium.
Silver, Nitrate, Crystals.
Soda Carbonate.
  " Sulphate.
Spirit, Pyroligneous, for spirit lamp.
Sulphur, Sublimed.
Tin Foil.
Tincture Galls.
  " Litmus.
  " Red Cabbage.

List of Apparatus.

Bladders, plain and mounted.
Cork Borers, set of five.
Crucibles, fire-clay.
Evaporating Basins.
Filtering Paper.
Flasks, plain, and with tubes for making gases.
Furnace Iron, with chimney.
  " " with sand-bath, &c.
  " Chauffers.
Funnels, Glass.
Gas Jars, plain, stopped and capped.
  " Holder, small.
  " " with Oxy-hydrogen Blowpipe.
Ladles, Iron, for supporting ignited Phosphorus, &c.
Lamps, Spirit.
  " Oil, with chimney.
Mortar and Pestle, Wedgewood.
Pneumatic Trough.
Test or Precipitating Glasses.
Retort Stands, iron, three rings.
Retorts, glass, plain and tubulated.
Retort, iron, for making oxygen.
Receivers, glass.
Scales and Weights.
Stirring Rods, glass.
Stop-cocks, brass.
  " jets.
  " connectors.
  Test tubes.

NATURAL AND EXPERIMENTAL PHILOSOPHY.

INTRODUCTION.

1. The general laws of nature are divisible into the four classes of, I. Physics, often called Natural Philosophy; II. Chemistry; III. Life, commonly called Physiology; and, IV. Mind.

2. The laws of Physics govern every phenomenon of nature in which there is any sensible change of place.

3. The great physical truths are reduced to four, and are referred to by the terms *Atom*, *Attraction*, *Repulsion*, and *Inertia*.

4. *Solid* bodies existing in conformity with these truths, exhibit all the phenomena of Mechanics; *Liquids* exhibit those of Hydrostatics and Hydraulics; *Airs* those of Pneumatics; and *Imponderables* those of Heat, Light, Electricity, and Magnetism.

MECHANICS.

LAWS OF MATTER AND MOTION.

5. Mechanics, in its most comprehensive sense, treats of the laws of rest and motion of material bodies. *Statics* treats of the equilibrium of solid bodies, and *Dynamics* treats of the motion of solid bodies. *Hydrostatics* treats of the equilibrium of fluid bodies, and *Hydro-dynamics* (*Hydraulics*) treats of the motion of fluid bodies.

6. MATTER is known to us by its properties, which affect our senses. The *mass* of a body is the quantity of matter which it contains. The *density* of a body is the comparative quantity of matter contained in a given size or volume.

7. MOTION. A body is in motion when it is in the act of changing its place.

When a body passes over equal spaces in equal successive portions of time, its motion is said to be *uniform*. When the successive spaces described in equal times continually increase, the motion is said to be *accelerated;* and when those spaces continually decrease, the motion is said to be *retarded.* Motion is *uniformly accelerated* or *retarded* when the increase or decrease of the spaces passed over in equal successive portions of time is always equal.

8. VELOCITY. The velocity of a body is measured by the space uniformly passed over in a given time.

When the motion of a body is accelerated or retarded, the velocity is not measured by the space actually passed over in a given time, but by the space which would have been passed over in the given time if the motion had continued uniform from that point.

9. MOMENTUM. The momentum of a body is its quantity of motion, and is measured by the weight of the body multiplied by its velocity.

The quantity of motion, or momentum, of a small body may be as great as that of a large body; for example, if the velocity of a musket ball be 100 times the velocity of a heavy hammer, which is 100 times the weight of the ball, then their momenta, or quantities of motion, will be the same. The deficiency of weight in the ball is made up by its excess of velocity.

When a person running strikes against an obstacle, he suffers a collision corresponding to his weight and the speed at which he is moving.

If two bodies moving in the same direction come into collision with each other, the force of collision is measured by the *difference* of their momenta; but if they are moving in opposite directions, the force of collision is much greater, for it is equal to the *sum* of their momenta. Hence it is that the collision of railway trains, when moving in opposite directions, is much more terrific than when they are moving in the same direction.

10. FORCE is that which produces, or tends to produce, motion in a body; or it is that which changes the uniform

and rectilinear motion of a body. Thus pressure, impulse, gravity, &c., are called *forces*.

When a force acts only for an instant, it is called *impulsive*; and when it acts without intermission, it is called a *constant* force. Constant forces may be either *uniform* or *variable*. A force is *uniform* when it always produces equal effects in *equal* successive portions of time; and it is *variable* when the effects produced in equal portions of time are *unequal*.

11. Matter is either ponderable or imponderable. *Ponderable* bodies have an appreciable weight; *imponderable* bodies comprise those subtile fluids which have no appreciable weight, such as *light*, *heat*, *magnetism*, and *electricity*.

12. Forces are known to us only by the effects which they produce.

In order to estimate the magnitude of forces, we must compare the effects which they produce under the same circumstances. A force may be estimated by the *pressure* which it produces upon some obstacle; or it may be estimated by the *motion* which it produces in a body in a given time. In the former case the measure of the force is said to be *statical*, and in the latter case *dynamical*.

PROPERTIES OF MATTER.

13. The properties of matter are usually divided into *primary*, or *essential*, and *secondary*, or *non-essential*.

The former are those without which we cannot conceive matter to exist; the latter are those which, depending upon the particular laws impressed upon different substances, do not necessarily enter into our abstract conceptions of matter; thus, for example, had it pleased the Creator, the law of gravitation might have been different from what it is; or, in the place of the law of perfect elasticity, observed in some bodies, all the forms of matter might have been practically incompressible. It is obvious, therefore, that the secondary properties of matter could not have become known to us anterior to observation and experiment. The relative adaptation of these secondary properties of matter to the conditions and constitution of the universe, affords the most striking evidence of the existence and attributes of a great and intelligent cause.

14. The primary properties of matter are *Extension* and *Impenetrability*. The most important secondary properties,

considered in relation to mechanical science, are *Compressibility*, *Expansibility*, *Divisibility*, *Cohesion*, *Elasticity*, *Mobility*, *Inertia*, and *Gravity*.

15. EXTENSION is that property whereby every body must occupy a certain limited space. We necessarily conceive every body to have length, breadth, and thickness.

16. IMPENETRABILITY is that property whereby no two substances can occupy the same space at the same instant of time.

17. COMPRESSIBILITY and EXPANSIBILITY are those properties by virtue of which bodies may be made to occupy a smaller or larger space.

The susceptibility to compression shows that all bodies must contain pores, or spaces between the ultimate particles or atoms of which they are composed, and that there is no substance in nature which is absolutely solid.

In consequence of these properties, bodies differ very much in density. When bodies have the same size, or volume, their densities are measured by their weights. Thus a cubic foot of copper weighs nine times as much as a cubic foot of water; hence copper possesses nine times the density, or specific gravity, of water.

18. DIVISIBILITY. There is no limit to the mathematical conception of the divisibility of space; but the doctrine of the atomic theory seems to indicate that there is a practical limit to the divisibility of matter.

In going on with our division, we must finally arrive at a certain *ultimate particle*, or atom of matter, which, from its constitution, no longer admits of separation into parts. Nature presents us with various marvellously minute divisions of the particles of matter.

19. COHESION, or the attraction of cohesion, is that property of bodies whereby the atoms composing them are united in a mass.

This force of attraction between the particles of matter only takes place at immeasurably minute distances. Bodies are solid, liquid, or aeriform, according as the cohesion of their particles is modified by heat. The particles of gases and vapors repel one another, in consequence of the repulsive force of heat being greater than the force of cohesion; in

solids, the force of cohesion preponderates over that of repulsion; and in liquids the forces of cohesion and repulsion are presumed to be equal.

20. ELASTICITY is that property of bodies by which, when their form is altered by the action of an external force, they regain their original form as soon as the external force is withdrawn.

All bodies possess this property in a greater or less degree.

Most substances have a limit to their elasticity: thus, if a straight elastic bar is bent by a pressure applied to it, and if this pressure does not exceed a certain quantity, the bar will resume its original form when this pressure is removed; but, on the contrary, if the pressure exceeds a certain quantity, called the limit of the body's elasticity, the cohesion of the material is injured or destroyed; and then, in this case, the bar will not return to its original form upon the cessation of the pressure. Bodies which have no elastic limit may be called perfectly elastic, such as gases and vapors.

Liquids scarcely admit of compression; and hence they are called *non-elastic fluids*, whereas gases and vapors are called *elastic fluids*. Some aeriform bodies, such as carbonic acid gas, have been brought to the liquid state by being subjected to a high pressure and cold; these are called *condensable gases;* whereas some gaseous bodies, such as oxygen and nitrogen, composing the atmosphere, resist condensation, whatever may be the pressure and cold to which they are subjected. These gases are called *permanently elastic*. Beams employed in construction are sometimes considered perfectly elastic, when their resistance to compression, within their limits of elasticity, is equal to their resistance to extension.

21. MOBILITY, or susceptibility to motion, is that property whereby a body admits of change of place.

Motion may be *absolute* or *relative:* thus a man in a railway carriage may be in motion *relatively* to the other objects in the carriage, while at the same time he partakes of the *absolute* motion of the train. In estimating motion, there are three things to be considered; viz., *the velocity* or quickness of the motion, *the space* passed over, and *the time* in which that space is passed over. The motion of a body is uniform when it passes over equal space in equal successive intervals of time; in this case, *the velocity* of the motion is the distance in feet passed over in one second of time; *the space* is the whole distance in feet moved over; and *the time* the number of seconds in which the space is described. In uniform motion, therefore, we have

$$\text{The space} = \text{the velocity} \times \text{the time.}$$

Here there are three general quantities, any two of which being given, the remaining one may be found.

Examples.

Ex. 1. If a railway train moves over 44 feet in a second, what space will it move over in an hour?

Space moved over in 1 sec. $= 44$ ft.

" " " 3600 sec. or 1 h. $= 3600 \times 44$ ft. $= 158,400$ ft. $= 30$ miles. Ans.

Ex. 2. If a railway train moves over 20 miles in an hour, what will be its velocity per second?

Space moved over in 3600 sec. or 1 h. $= 20 \times 5280$ ft.

$$\text{Or, in 1 sec.} = \frac{20 \times 5280}{3600} = 29\tfrac{1}{3} \text{ ft. Ans.}$$

Ex. 3. If the velocity of a body be 20 feet per second, in what time will it move over a mile?

$$\frac{5280 \text{ ft.}}{20 \text{ ft.}} = 264 \text{ sec.} = 4\tfrac{2}{5} \text{ min. Ans.}$$

22. Inertia. By this property is meant that matter has no power in itself to change its present state, and that any alteration in its state, whether of rest or motion, must be produced by the action of some external force.

If a body is broken, some force must have produced the rupture. If a body is melted, heat must have produced the change. If a body changes its state from rest to motion, some force must have communicated the motion. If it passes from a state of motion to that of rest, some force must have been exerted to destroy the motion. The laws of motion will be hereafter more fully considered.

Experiment. Place a penny on a piece of card paper, and balance it upon the tip of one of the fingers of the left hand, as shown in Fig. 1;

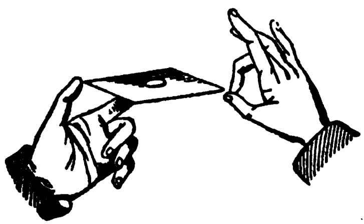

Fig. 1.

give the card a smart blow with one of the fingers of the right hand;

the card will be projected forward, but the penny, from its inertia, will remain on the finger.

When a carriage suddenly stops, the person in it is liable to be thrown forward, from the inertia of his body; that is, in this case, from the tendency which his body has to continue in motion.

A body in motion also tends to move forward in a straight line; hence the effort we have to make when we run round a corner. When a stone is whirled round in a sling, it flies off in a direct course the moment it is allowed to escape. It is well known that a hare, acting by instinct on this law of inertia, sometimes makes its escape from the greyhound by taking a great many sudden turns, which the dog, from its greater bulk and inertia, does not so readily take. Thus, in running to the cover C, (see Fig. 2,) the hare takes the course A B D E C, while the dog is compelled to take the longer course, A b d e C.

Fig. 2.

When the equestrian, standing on the saddle, leaps over a cord extended over the horse at right angles to his motion, the horse passes under the cord while the rider leaps over it, and lights on the saddle at the opposite side. Here the equestrian has merely to leap upwards, not forwards, as he would have to do if he were not in motion; for while in the act of leaping he retains the motion which he had before he made the leap, so that, when he arrives at the opposite side of the cord, his progressive motion being the same as that of the horse, he lights exactly on the saddle.

23. Gravity is that property by which all terrestrial bodies tend towards the centre of the earth. When a body is supported, this tendency produces *pressure* and *weight*.

The pressure produced by gravity is always exerted in a direction perpendicular to the horizon, and is measured by the weight of the body. The unit of weight in mechanical calculations is a pound; and hence the forces of pressure are usually expressed in units of pounds.

It has been found by experiment (allowance being made for the resistance of the air) that bodies of every size, shape, and weight fall to the earth exactly in the same manner. Thus, were it not for the resistance of the air, a feather and a guinea would fall from the top of a tower in the same time, and they would strike the ground with the same velocity.

Experiment. Take a small piece of thin paper and a coin, and let them fall the same instant from equal heights above the ground; then the coin will arrive at the ground much sooner than the paper. Here the air presents a greater proportional resistance to the motion of the light body than it does to the heavy one; but, in order that the resistance of the air may be the same in both bodies, place the paper on the coin, and then let them fall together; they both arrive at the ground at the same instant.

Thus it appears that the pressure produced by the earth's attraction upon bodies is a very different thing from the motion which it generates. In the former case, the pressure produced is proportional to the quantity of matter; whereas, in the latter case, the motion generated in a given time is the same for all bodies, whatever may be their size, weight, or density. This admits of a satisfactory explanation: the earth attracts every particle of which a body is composed, and hence the weight of a body depends upon the matter which it contains. On the other hand, all the particles of a body separated from one another would evidently fall through the same spaces in the same time; but it appears from experiment, that when the particles are collected in one mass, they fall exactly in the same manner as they would if they were separated from one another.

24. Gravity is said to take place in consequence of the attraction exerted by the earth upon the body. The general name given to this force is that of *attraction of gravitation.*

This force is not confined to bodies upon the earth's surface; the moon is maintained in her orbit by the attraction of the earth, and all the planetary bodies in the solar system are subject to the attraction of the sun.

The attractive force exerted by bodies on each other is reciprocal, and in proportion to their masses.

Thus, if the body A attracts the body B, then B will attract A, and the forces which they exert on each other will be proportional to their respective masses.

Again, the force of attraction varies inversely as the square of the distance.

Thus at double the distance the force will be one fourth, at treble one ninth, and so on.

These two laws are expressed by saying that the force of

gravitation varies directly as the mass, and inversely as the square of the distance.

Bodies are attracted by the earth as if the whole of its mass were collected in its centre; hence the force of gravity at any place depends upon the distance of the place from the centre of the earth. Now, since the equatorial diameter of the earth is greater than the polar diameter, it follows that the force of gravity at places near the equator is not so great as it is at places near the poles; thus it is found that a body which produces by its gravity a certain pressure at Boston, would not produce this amount of pressure if taken to the equator; and in like manner a pendulum which beats seconds at Boston would take a longer time to complete a vibration at the equator.

In consequence of the constant action of the force of gravity, the motion of a falling body becomes quicker and quicker as it descends. In one second a body will fall through $16\frac{1}{12}$ feet; but the velocity acquired in one second is $32\frac{1}{6}$ feet, in two seconds it is twice $32\frac{1}{6}$, in three seconds it is three times $32\frac{1}{6}$, and so on. That is, *the velocity acquired by a falling body increases with the time*; or, in other words, the velocity acquired by a falling body in feet is equal to the product of $32\frac{1}{6}$ feet by the number of seconds of its fall.

Experiment. If a body takes three seconds in falling from the top of a tower, with what velocity will the body strike the ground?

$$\text{Velocity} = 3 \times 32\tfrac{1}{6} \text{ ft.} = 96\tfrac{1}{2} \text{ ft.}$$

This law of acquired velocity arises from the fact that gravity is a *uniformly accelerating force*, communicating equal increments of velocity in equal times, and that each successive increment of velocity is unaffected by the motion previously acquired. At places towards the equator the accelerating force of gravity is less than it is in our latitude, and at places near the poles it is greater. The laws of descending bodies will hereafter be more fully considered.

25. CENTRE OF GRAVITY. The centre of gravity of a body is that point in it where all the matter composing it may be supposed to be collected. The centre of gravity of any regular body lies in its centre of magnitude.

Balance a rod or a stick, or any other body, upon the finger; that point upon which the body is balanced is the centre of gravity. If the centre of gravity of a body be supported, the body will remain at rest; and in all other positions the centre of gravity descends to the lowest place to which it can get.

A vertical line drawn through the centre of gravity of a body is called

the *line of direction*. If the line of direction fall within the base, the body will stand; if not, it will fall. Thus,

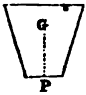

Fig. 3.

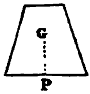

Fig. 4.

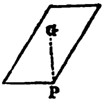

Fig. 5.

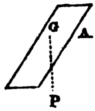

Fig. 6.

let G G, &c., be the centres of gravity of four bodies standing on their horizontal bases, and G P, G P, &c., the lines of direction; then the bodies represented in Figs. 3 and 4 will stand, because the lines of direction fall within their bases. The body represented in Fig. 5 will be upon the point of falling, because the line of direction just falls at the edge of its base; and the body represented in Fig. 6 will fall, because the line of direction falls without its base.

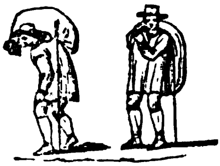

Fig. 7.

When a man carries a load upon his back, he leans forward, to bring the centre of gravity of his body and the load which he carries within the base formed by his feet. If he were not to do so, the load would be liable to draw him over backward. For the same reason, when a man walks up a hill he leans forward, and when he descends he leans backward.

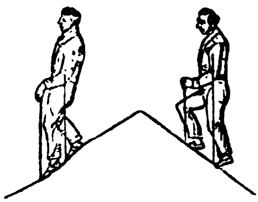

Fig. 8.

A cylinder may be made to roll up an inclined plane. Fix a piece of lead, *s*, in one side of the cylinder *z*; then it will roll up the inclined plane to the position

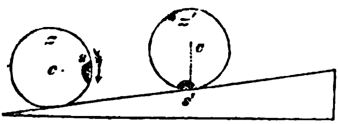

Fig. 9.

z' s', because the centre of gravity of the mass will endeavor to descend to its lowest point.

If a body be supported by a point lying above its centre of gravity, the body is said to be suspended, and if it be free to move, it will not rest until its centre of gravity has attained the lowest possible position. Thus, for example, if the ball K be suspended by the thread *s a*, it will not rest until its centre of gravity, *s*, attains the lowest possible position, that is, in this case, when the thread hangs vertically.

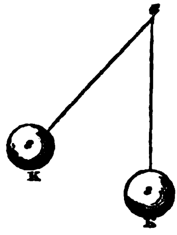

Fig. 10.

Fig. 11 shows how two forks may be suspended on the point of a needle. Stick two forks, A and B, into a cork, C; then stick a sewing needle, with its point outwards, into the cork, and poise the whole on the top of a wine glass, or on the head of a pin stuck into another cork. Here the stability of the system depends upon the fact, that the centre of gravity is below the point of support.

In like manner a fork may be suspended over the edge of the table on the point of a needle, as shown in Fig. 12. Here the point of suspension, P, lies in the vertical line, P C, passing through the centre of gravity, C, of the fork.

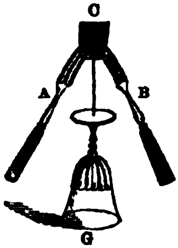

Fig. 11.

To find the centre of gravity of any plane surface, suspend it freely by any point, and draw the line of direction through that point of suspension; suspend the surface by another point, and in like manner draw the line of direction through it; then the intersection of these two lines will give the centre of gravity of the surface.

Of all forms of structure, having the same height and base, the pyramidal form is the strongest. The pyramid represented in Fig. 13, which stands on a broad base, is more stable than that represented in Fig. 14, which has a narrow base; because the centre of gravity, G, must be raised through a greater space in the former case than in the latter case, before they can be overturned.

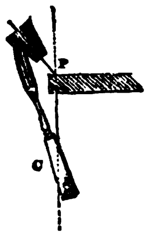

Fig. 12.

The body, A B C, (Fig. 15,) has a position of *stable equilibrium*, because its centre of gravity, C, has attained its lowest possible position; whereas the body represented in Fig. 16 has a position of *unstable equilibrium*, because its centre of gravity, C, has not attained its lowest possible position; the slightest force will cause its centre of gravity to descend, and to occupy the position represented in Fig. 15.

A cart loaded with *stone* may pass safely along a road of which one

side is higher than the other; but if the same cart were loaded with *hay*, it would be overturned; for, though the sustaining base be the same in

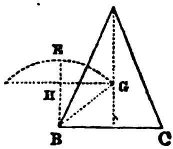

Fig. 13.

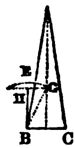

Fig. 14.

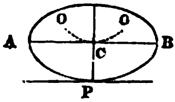

Fig. 15.

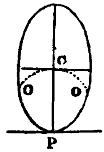

Fig. 16.

both cases, the *line of direction* falls much within it from the low centre of gravity of the stone, but very near the wheel, or altogether on the outside, from the high centre of the hay.

The feet of our common chairs, and of tripods, are generally expanded below to give a broad base. The high chair, to accommodate the little child at the dining table, is very dangerous if the feet do not spread much.

The famous leaning tower of Pisa is believed to have been purposely so built. Its height is 130 feet; and though its top overhangs the base 16 feet, the line of direction falls within the base.

The upright form of man stands firmly on a very narrow base, which is the space occupied by his feet. The advantage of turning out the toes is, that without taking much from the length of the base, it adds to its breadth.

A person on rising from a chair first bends the body forward so as to bring the feet under the centre of gravity, and then lifts the body.

When a man walks at a moderate rate, his centre of gravity comes alternately over the right and over the left foot, causing the body to advance in a waving line. Persons walking arm in arm jostle each other, unless the movement of their feet correspond as do those of soldiers in marching.

LAWS OF MOTION.

26. First Law of Motion. A body in motion will move continually in a straight line, and with a uniform velocity, if it is not acted on by any external force.

Many persons are apt to think that a body in motion would stop of itself; but this is not correct, for it is only the obstacles which a body in motion meets with that causes it to stop. Thus, when a body is rolled along a floor, the *friction* of the floor causes the body to come to a state

of rest; but we know that the smoother the floor the farther will the body roll. The *resistance of the air* also tends to stop bodies in motion. Hence it is that a wheel with vanes will revolve much longer in the exhausted receiver of an air pump than it will do in the open atmosphere. *Gravity* also tends to destroy motion: a body thrown upward soon loses its motion, and returns to the earth's surface.

Whenever, therefore, a body in motion comes to a state of rest, we may safely infer that some external force or resistance has checked the motion; and that a body in motion would never stop, that is to say, it would move on and on in a straight line for ever, if it did not meet with any external force or resistance to stop it.

SECOND LAW OF MOTION. If any number of forces act at the same instant upon a body in motion, each force produces its full effect in the direction of its action, just as if it had acted alone upon the body at rest.

Thus, if a ball be dropped from the top of the mast of a ship moving uniformly, the ball strikes the deck at the bottom of the mast, and falls precisely in the same time as if the ship were at rest.

Although the earth, by its diurnal motion, carries all bodies on its surface uniformly from west to east, yet all motions take place on the earth's surface just as if it were at rest.

If a ball be thrown along the deck of a vessel moving uniformly, it

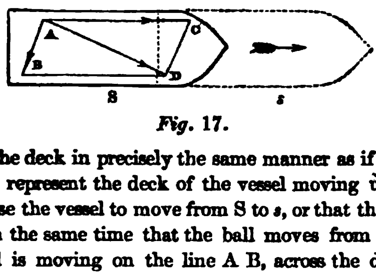

Fig. 17.

will move on the deck in precisely the same manner as if the vessel were at rest. Let S represent the deck of the vessel moving uniformly in the water. Suppose the vessel to move from S to *s*, or that the point A moves from A to C in the same time that the ball moves from A to B. Now, whilst the ball is moving on the line A B, across the deck, it is at the same time carried with the vessel from A to C, and at the end of the time the ball is found at D; so that it preserves its two motions; that is to say, it moves in the direction A B as if it had no other motion, and in the direction A C with the vessel, as if it had no other motion. The actual path pursued by the ball is evidently in the diagonal, A D, of the parallelogram, A B D C.

This establishes what is called the *parallelogram of motion*, which may be enunciated as follows: —

Parallelogram of Motion. If two velocities be given to a body at the same instant, the actual velocity will be represented by the diagonal of the parallelogram formed upon the two lines representing the velocities impressed upon the body.

Let a body at A (Fig. 17) have a velocity given to it which would cause it to move uniformly from A to C in a given time, and another velocity at the same instant, which would cause it to move uniformly from A to B in the same time. Now, if the parallelogram, A B C D, be completed, the actual path of the body will be the diagonal, A D, described in the same time.

When a boatman is rowing his boat (Fig. 18) across a strong stream, the boat has two distinct impulses given to it; the impulse given by the man, which tends to carry the boat directly across the stream, from A to B, and that of the stream itself, which tends to carry the boat along with it from A to D. Under the action of these two simultaneous impulses the boat moves in the direction of the diagonal, A C.

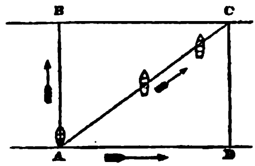

Fig. 18.

Very nearly allied to the parallelogram of motion is the *parallelogram of forces*.

The parallelogram of forces is this: if the sides A D and A B (see Fig. 19) of the parallelogram, A B C D, represent the magnitude and direction of two forces acting at the same moment on the body, A, then the diagonal, A C, will represent the magnitude and direction of the resultant force, or the single force which the two forces acting together produce.

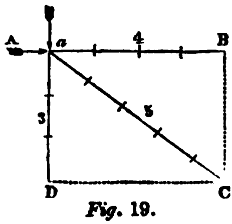

Fig. 19.

Thus, if the body, A, be pressed in the direction A B with a force of 3 pounds, and at the same time in the direction A D with a force of 4 pounds, then these two forces acting together will produce a single force whose direction and magnitude may be readily found by constructing the parallelogram of forces. From any scale of equal parts take A B, equal to 3 units, representing the force in the direction A B; from the same scale take A D, equal to 4 units, representing the force in the direction A D; construct the parallelogram, A B C D; then the diagonal, A C, will be the direction of the single resulting force, and the units in A C will be the magnitude of this force, viz., 5 pounds.

THIRD LAW OF MOTION. Action and reaction are always equal and contrary.

If a person presses the table with his finger, he feels a resistance arising from the reaction of the table; and this counter-pressure is equal and contrary to the downward pressure. When a horse draws a load forward, he is pulled backward by the load. When a gun is fired, the explosion of the powder, which gives the forward motion to the ball, at the same time gives the recoil to the gun. When a bird flies, it strikes the air downward with its wings, and thereby produces a reaction sufficient to support it in the atmosphere. If a man in a boat pull another boat towards him, by means of a rope, then, from the law of action and reaction, both boats will move towards each other in such manner that their momenta shall be equal.

If an elastic ball be projected in a direction perpendicular to the surface of a hard pavement, the reaction will cause the ball to rebound in

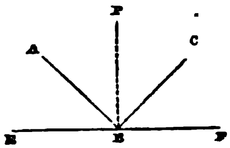

Fig. 20.

the direction in which it was projected. Now, if the ball be projected obliquely, it will rebound obliquely, making the angle of reflection equal to the angle of incidence.

The intensity of the action of any force is estimated by the mass and velocity of the body which it sets in motion; that is to say, by the momentum of the body which it sets in motion. Thus, if a cannon ball be fifty times the weight of a musket ball, but the musket ball be moved with fifty times the velocity of the cannon ball, then both balls will have the same momentum, and will strike any obstacle with the same force. Again, let A and B be two bodies in motion; A weighs 8 lbs., and moves with the velocity of 3 feet per second; B weighs 4 lbs., and move with the velocity of 6 feet per second; then

wt. $\times$ velo.
$8 \times 3 = 24$, momentum A.
$4 \times 6 = 24$, momentum B.

that is to say, the momenta, in this case, are equal, and the quantities of motion in them are equal, and the intensity of the forces producing these motions are equal.

If a body in motion impinges upon another body, the quantity of motion, or momentum, of the two bodies after impact will be the same as it was before impact: the momentum lost by the one body is exactly the same as that which is gained by the other body; and this is true whether the bodies be elastic or non-elastic.

Ex. 1. Let A and B be two non-elastic bodies moving in the same direction, and that A impinges upon B; let the weight of A be 6 lbs., and its velocity 8 feet per second, and the weight of B 2 lbs., and its velocity 4 feet per second; required the velocity with which the two bodies will move on together after impact.

Here the momentum of A before impact $= 6 \times 8 = 48$;

Momentum of B before impact $= 2 \times 4 = 8$;

Momentum of mass after impact $= 48 + 8 = 56$.

Now, as the bodies are non-elastic, they will move on together, after impact, with the same velocity. But the common velocity of the two bodies will be found by dividing their momentum by the sum of their weights, which, in this case, is 6 lbs. + 2 lbs. = 8 lbs.

Velocity of the bodies after impact $= \frac{56}{8} = 7$ ft. per sec. *Ans.*

Ex. 2. Required the same as in the last example when the bodies move in opposite directions.

In this case the momentum of B must be subtracted from the momentum of A; thus,

Momentum after impact $= 48 - 8 = 40$;

Velocity of the bodies after impact $= \frac{40}{8} = 5$ ft. per sec. *Ans.*

When the bodies are elastic, the case is somewhat different; for they do *not* move on together after impact with a common velocity, owing to the reaction of the elastic material of which the bodies are composed.

The equality of action and reaction in the collision of bodies may be illustrated by the following simple experimental apparatus: A and B are two balls suspended by equal strings, A C and B C, so that the balls may be in contact with each other; E F is a graduated arc, of which C is the centre, over which the balls may oscillate. One of the balls, A, is drawn aside along a certain number of the arc, and then allowed to fall and strike the other ball, B, which will, in consequence of the collision, move up the other portion of the arc. The velocity with which A impinges upon B is measured by the number of degrees of the arc through which it falls, and the velocity of the bodies after impact is measured by the number of degrees of the arc through which they ascend.

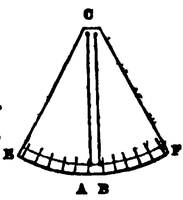

Fig. 21.

Exp. 3. Let the two balls be composed of soft clay, or any other non-elastic substance; then after impact they will move on together with a common velocity, which may be calculated, as in *Ex.* 2.

Suppose the balls to be equal in weight, and that A impinges upon B at rest; then the two balls will move together with a velocity due to that which A had at the moment of impact. And so on to other cases, which may be readily verified by experiment.

Let the two balls be composed of ivory, or any other substance which is nearly perfectly elastic, and let them be of the same size. Suppose the ball A to impinge upon the ball B at rest; then after impact A will remain at rest, and B will move on with the same velocity as A had at the moment of impact. In this case the reaction of elasticity causes the ball A to stop, and the ball B to move forward with the motion which A had at the instant of impact. And so on to other cases, which may be readily verified by experiment.

EFFECTS OF GRAVITY.

Falling Bodies.

27. It has already been explained that, since gravity is a constantly acting force, it causes bodies to fall quicker and quicker in the course of

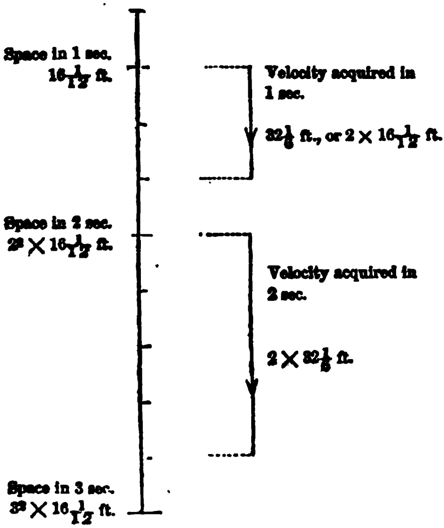

Fig. 22.

their descent, and that the velocity acquired at any instant is proportional to the time of descent. Now, in 1 second a body falls through $16\frac{1}{12}$ feet; in 2 seconds it falls through 4 times $16\frac{1}{12}$ feet, or $64\frac{1}{3}$ feet; in 3 seconds it falls through 9 times $16\frac{1}{12}$ feet, or $144\frac{3}{4}$ feet; and so on, the law of descent being as follows: *the space passed over by a falling body is equal to* $16\frac{1}{12}$ *feet multiplied by the square of the number of seconds during which the body has been falling.* Thus the space moved over in 3 seconds is equal to $3^2 \times 16\frac{1}{12}$ feet $= 144\frac{3}{4}$ feet, and the space moved over in 4 seconds is equal to $4^2 \times 16\frac{1}{12}$ feet $= 257\frac{1}{3}$ feet; and so on.

Fig. 22 shows the relation between the time, space, and velocity acquired by a falling body.

A glance at Fig. 22 will show that the spaces fallen through in each successive second are as the numbers 1, 3, 5, 7, &c.; that is to say, for example, the space fallen through *during* the 3d second will be equal to 5 times $16\frac{1}{12}$ ft., or $80\frac{5}{12}$ ft.

Ex. 1. Through what space will a body fall in 5 sec.?

Ans. $402\frac{1}{12}$ ft.

Ex. 2. Through what space will a body fall in $2\frac{1}{2}$ sec.?

Ans. $100\frac{25}{48}$ ft.

Ex. 3. What space will a body descend during the 4th second of its fall? *Ans.* $112\frac{7}{12}$ ft.

Ex. 4. In what time would a body acquire a velocity of $160\frac{5}{6}$ ft.?

Ans. 5 sec.

When a body is projected vertically upward, its motion is uniformly retarded, and it will rise to the same height as that from which it would have to fall in order to acquire the velocity of projection.

Thus, for example, if the body be projected vertically upward with a velocity of 3 times $32\frac{1}{6}$, the force of gravity will destroy all its motion in 3 seconds, so that the height to which it will rise will be equal to $3^2 \times 16\frac{1}{12}$ ft. $= 144\frac{3}{4}$ ft.

Ex. 1. If a body be projected vertically upward with a velocity of 193 ft. per second, to what height will it ascend? *Ans.* 579 ft.

Ex. 2. If a body be projected vertically upward with a velocity of $64\frac{1}{3}$ ft., in what time will it return to the ground? *Ans.* 4 sec.

Projectiles.

28. When a body is projected obliquely in the air, it describes a curved line, which is called a *parabola*.

Were it not for the force of gravity, the body, according to the first law of motion, would move uniformly on in the direction of the straight line in which it is projected; but the force of gravity causes it to be deflected from this straight line; so that, under the combined action of the force of projection and that of gravity, the body moves in a curved line. When the body reaches the highest point, it descends in a curve which is exactly the same as the curve which it pursued in its ascent.

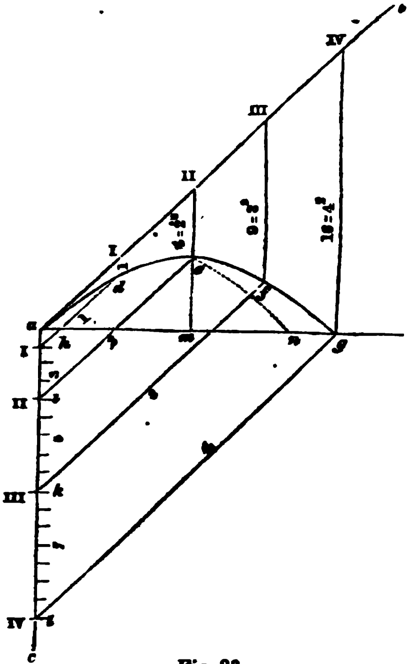

Fig. 23.

Let a body be projected in the line *a b* (see Fig. 23,) with a velocity which would carry it (if gravity were not acting) from *a* to I in 1 second, from *a* to II in 2 seconds, and so on; then the path of the body will be in the parabola *a d e f g*, where *e* is the highest point of ascent, and the curve *e f g* of descent has the same form as the curve *a d e* of ascent. The path of the projectile may be found in the following manner:—

Draw the vertical *a c*; take *a h* = $16\frac{1}{12}$, the space through which a

body will fall in 1 second; $a\,l = 4 \times 16\frac{1}{12}$, the space through which a body will fall in 2 seconds; $a\,k = 9 \times 16\frac{1}{12}$, the space through which a body will fall in 3 seconds; and so on: draw $h\,d$, $l\,e$, $k\,f$, &c., parallel to $a\,b$, and, intersecting the verticals drawn through the points I, II, III, &c., in the points d, e, f, &c., then the path of the projectile will be in the curve $a\,d\,e\,f\,g$.

The Pendulum.

29. The *times of the vibrations* of the pendulum are very nearly equal, whether it be moving much or little; that is to say, whether the arc described by it be large or small.

Hence it is employed to regulate the machinery of our clocks. The time which a pendulum takes to make a vibration depends upon its length; it is well known that the longer the pendulum the greater is the time which it takes to perform a vibration. It has been ascertained that the lengths of different pendulums vary as the squares of their respective times of vibrations: thus, a pendulum which vibrates in 3 seconds must be nine times the length of a pendulum which vibrates in 1 second; a pendulum which vibrates in half a second must be a quarter the length of a pendulum which vibrates in 1 second; and so on. The length of a pendulum vibrating seconds at London is about $39\frac{1}{5}$ inches, and therefore the length of a pendulum to vibrate half-seconds must be the quarter of $39\frac{1}{5}$ inches, or about $9\frac{4}{5}$ inches.

Motion round a Centre.

30. When a body moves round a centre, it is acted upon by two forces, viz., the force of *projection*, which gives the body motion, and the *centripetal* force, or centre-seeking force, which retains it in its circular path, thereby preventing it from flying off in a straight line, or in a tangent line to the curve. This tendency to fly off in a tangent is called the *centrifugal* force, or centre-flying force. This force is counteracted by the centripetal force.

Such is the motion of the planets round the sun, and the satellites round their respective primaries. The gravitation of the planets towards the sun is the centripetal force, and the force of projection we assume to have been at first given to the various planets by the hand of the Creator.

One of the most familiar instances of motion round a centre is the

whirling motion given to a stone in a sling. Here the propelling force, or the force of projection, is given by the hand, and the centripetal force is exhibited in the tension of the string; when we quit the string, the centripetal force no longer acts, and the stone, by the action of the centrifugal force generated by the whirling motion, flies off at a tangent.

When we whirl a mop, the water flies from it by the action of the centrifugal force, and the threads of the mop assume the form of a spheroid, or of a sphere flattened at the poles of revolution. In like manner the earth is a great globe flattened at the poles. The rotation of the earth upon its axis has caused the equatorial parts to bulge out.

When a carriage is moved rapidly round a corner, it is very liable to be overturned by the centrifugal force thus brought into action.

When an animal moves round in a circle, he leans towards the centre, in order to counteract the centrifugal force.

When railways form a rapid curve, the outer rail, D, (Fig. 24,) is laid higher than the inner rail, E, in order to counteract the effect of the cen-

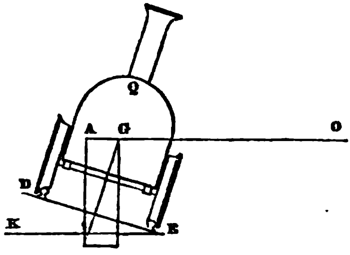

Fig. 24.

trifugal force, which, acting through the centre of gravity, G, of the carriage, has a tendency to throw it off the line. The rise, K D, of the outer rail will of course depend upon the quickness of the curve and the breadth of the rail.

The following instructive experiment is sometimes performed by conjurers: A B is a hoop which revolves upon an axis, O; W is a wine glass of water placed within the hoop. Now, when a rapid motion of rotation is given to the hoop, the wine glass of water is sustained in its place by the centrifugal force that is thus generated; and if the experiment be carefully made, not a single drop of water will be thrown from the glass.

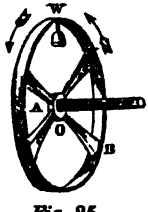

Fig. 25.

LABORING FORCES.

81. When work is performed by any agent, there is always a certain weight or resistance moved over a certain space. The amount of work done will obviously depend upon the weight or resistance that is moved, and the space over which it is moved. In order to estimate the amount of work done by any laboring force, it is requisite that we should fix upon some *unit of work*. Now, the unit of work adopted in this country is the labor expended in raising a pound weight one foot high in opposition to gravity; or, what amounts to the same thing, it is the labor expended in moving a resistance of one pound through the space of one foot in opposition to the direction in which the resistance acts. From this definition of a unit of work it follows, that

The work expended in raising any body in opposition to gravity is equal to the product of its weight in pounds by the vertical space in feet through which it is raised.

For example, the work expended in raising 50 lbs. to the height of 20 feet will be equal to $50 \times 20 = 1000$.

In calculating the work requisite to pump water from a mine, it is only necessary that we should find the weight of the water in pounds, and then multiply this result by the depth of the mine in feet.

When a horse draws a carriage along a road, the work which he performs is expended in overcoming the resistance of the friction of the road to the motion of the carriage. Now, on any given road, this resistance of friction is simply proportional to the weight of the load; so that, in calculating the work, we allow so many pounds' resistance for every ton weight in the load. The work in this case will be found by multiplying the total resistance of friction in pounds by the space in feet over which the carriage is moved.

It is also customary to express work in units of *a horse power*. Watt estimated that a horse could perform 33,000 units of work per minute; this work, therefore, is called a horse power. In order, therefore, to determine the number of horse powers of an engine requisite for performing a certain amount of work, we must first find the number of units of work which must be done per minute, and then divide this result by 33,000 to find the number of horse powers.

EXAMPLES.

Ex. 1. How many horse powers would it take to raise 2 cwt. of coals per minute from a pit whose depth is 100 fathoms?

Weight of the coals in lbs. $= 2 \times 112 = 224$;

Depth of the pit in feet, $= 6 \times 100 = 600$;
Work to be done per min., $= 224 \times 600 = 134.400$;

No. of horse powers, $= \dfrac{134,400}{33,000} = 4.07$, *Ans.*

Ex. 2. Required the same as in the last example, when the weight of the coals is 1 cwt., and the depth of the pit is 400 fathoms.

Ans. 8.14.

Ex. 3. How many horse powers would be required to raise 1000 cubic feet of water per hour from a mine whose depth is ninety fathoms?

Weight of water in lbs. $= 62.5 \times 1000 = 62,500$ lbs.;
Depth of the mine in feet $= 6 \times 90 = 540$ feet;
Work to be done per hour $= 62,500 \times 540$;

Work to be done per min. $= \dfrac{62,500 \times 540}{60} = 62,500 \times 9$;

No. of horse powers $= \dfrac{62,500 \times 9}{330,00} = 17$, *Ans.*

Ex. 4. Required the same as in the last example, when the number of cubic feet of water $= 1250$, and the depth of the mine $= 43$ fathoms.

Ans. 10.1.

Ex. 5. If a man can perform 2500 units of work per minute, in what time will he pump 100 cubic feet of water from a well whose depth is 500 feet?

Work to be done $= 100 \times 62.5 \times 500$;

Time to do the work $= \dfrac{100 \times 62.5 \times 500}{2500} = 1250$ minutes, $= \dfrac{1250}{60}$ $= 20.83$ hours, *Ans.*

Ex. 6. Required the same as in the last example, when the number of cubic feet of water $= 50$, and the depth of the well $= 250$ feet.

Ans. 5.2 hours.

Ex. 7. What must be the horse powers of a locomotive engine which moves at the steady speed of 30 miles per hour, on a level rail, the weight of the train being 25 tons, and the resistance of friction at the rate of 8 lbs. for every ton?

Total resistance of friction $= 8 \times 25 = 200$ lbs;

Distance this resistance is moved over in ft. per min. $= \dfrac{30 \times 5280}{60}$ $= 2640$ feet;

Work to be done every minute $= 200 \times 2640$;

Horse powers of the engine to do this work $= \dfrac{200 \times 2640}{33,000} = 16$ horse powers, *Ans.*

Ex. 8. Required the same as in the last example, when the speed $=$ 25 miles, and the weight of the engine $= 60$ tons.

Ans. 32 horse powers.

General Views relative to Machines.

32. The object of machinery, properly so called, is to regulate the distribution, or change the direction of work, not to increase it. If there were no friction or any other resistances to the motion of the pieces composing a machine, the work that would be given out would be exactly equal to the work applied. Dead matter, by its gravity, produces pressure, and by the intervention of mechanism, that pressure may be increased or decreased; but *work* is peculiarly the production of active or living agents. To suppose that machines are capable of augmenting work would be endowing inert matter with a creative power—the power of creating work.

In all instances of labor performed by inanimate matter, there is some active agent of nature, such as heat, electricity, or gravitation, which gives rise to the work; but, in the case of merely mechanical arrangements, the inert matter is the passive recipient of work, or the channel through which it flows. Hence we may lay it down as a fundamental axiom in mechanics, that (abstracted from friction and the resistance of the air) *the work done by any machine is the same as the work applied.* Now, as the work is the product of pressure and motion, it follows that, if the working point of a machine moves more slowly than the driving point, then the pressure at the former will be greater than it is at the latter. Thus, for example, if the power applied to the extremity of a lever moves twice as fast as the weight or resistance at the other extremity, then the pressure of the power, in order to raise the weight, must be only one half of the pressure of the weight or resistance, for then the work applied by the power would be exactly equal to the work done in raising the weight or resistance. So, in like manner, in any arrangement of wheels or pulleys, if the power applied moves say nine times as fast as the resistance or weight to be raised, then the pressure of the power, in order to raise the weight, must be only one ninth of the pressure of the weight or resistance.

Thus it appears, from the principle of the equality of work, that where the power applied to a machine is just able to raise the weight or resistance, *the power and the weight will be to each other inversely as their velocities;* or, in other words, the weight moved will be as many times greater than the power applied to move it, as the velocity of the power is greater than that of the weight. Now, the number of times that the weight is greater than the power is called the advantage gained by the machine. Hence the advantage gained is equal to the number of times that the velocity of the power is greater than that of the weight; or, in more precise language,

The advantage gained by a machine is equal to the

velocity of the power divided by the velocity of the resistance.

This is sometimes called the principle of virtual velocities. Practical men express this law by saying, "*What you gain in power you lose in speed.*"

MECHANICAL POWERS.

The *simple machines*, or *mechanical powers*, as they have been called, — the lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw, — enable man to adopt any species and speed of power which he can command, to almost any work which he has to accomplish. But, as we have already explained, the advantage gained is simply an advantage of pressure, not of work; for what is gained in pressure is lost in speed, and therefore the actual amount of work done by means of the mechanical power is neither increased nor decreased; indeed, if the friction of the parts of the machine is taken into account, the work done by it is really less than that which would be done by the man laboring without the intervention of such machinery.

The Lever.

33. The lever is an inflexible bar or rod, turning on a pivot, which is called the *fulcrum*. It is used for raising heavy weights over a short distance.

No. 1. No. 2.

Fig. 26.

Thus, P W, (Fig. 26) represents a crowbar or lever, W the resistance, F the fulcrum, and P the point at which the power is applied.

Fig. 27 represents a lever; C, the fulcrum or centre of motion; P C, the arm to which the pressure of the power, P, is applied; and C W, the arm to which the pressure of the weight, or resistance, W, is applied.

Now, when the lever comes to the position *p w*, the power, P, has

moved over the arc P *p*, while the weight W has moved over the arc W *w*; these arcs, therefore, respectively represent the velocities of P and W.

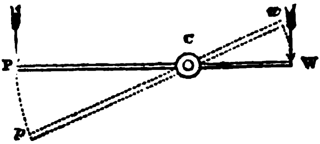

Fig. 27.

Here, if the arm C P were double the arm C W, the velocity of P would be double that of W, for a double radius would sweep over a double arc; and if the arm C P were three times the length of the arm C W, the velocity of P would be three times that of W; and so on: so that the velocity of the power is as many times the velocity of the weight as the arm by which the power acts is longer than the arm by which the weight acts; and therefore, from what has been explained, the advantage gained will be found by finding the number of times that the arm C P is greater than the arm C W; thus, if C P be 3 times the length of C W, the advantage gained will be 3, and a pressure of 1 cwt. at P will raise a resistance or weight of 3 cwt. at W. Again, if C P = 5 feet, and C W = ½ foot, then the advantage gained will be 10, because 5 feet are equal to 10 times ½ foot; and so on to other cases.

34. Levers are divided into three kinds, according to the relative positions of the power and weight with respect to the fulcrum.

Fig. 28 represents a lever of the *first kind*, where the power P and weight W act on opposite sides of the fulcrum F. Fig. 26, No. 1, also represents a lever of the first kind.

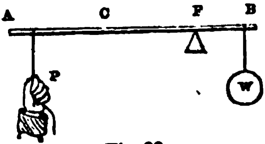

Fig. 28.

Fig. 29 represents a lever of the *second kind*, where the power P and weight W act on the same side of the fulcrum F; but W is nearer to the fulcrum than P. Fig. 26, No. 2, also represents a lever of the second kind.

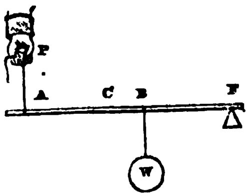

Fig. 29.

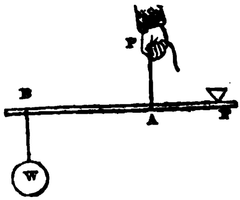

Fig. 30.

Fig. 30 represents a lever of the *third kind*, where the power, P, and weight, W, act on the same side of the fulcrum, F; but P, in this case, is nearer to the fulcrum than W.

When a man raises a ladder against a wall, (see Fig. 31,) he employs a lever of the third kind. In this case, the fulcrum is at the foot of the ladder, the power is applied by the hand of the man, and the resistance is the weight of the ladder itself, which acts through its centre of gravity, G.

Fig. 31.

In the lever of the second kind, (see Fig. 29,) if the arm A F, by which the power acts, is 5 feet, and the arm B F, by which the weight acts, is 2 feet, then the advantage gained will be $5 \div 2 = 2\frac{1}{2}$; that is to say, a power of 1 cwt. applied at A will just balance a weight of $2\frac{1}{2}$ cwt. applied at B, and a power of 60 lbs. applied at A will balance a weight of $2\frac{1}{2}$ times 60 lbs., or 150 lbs., applied at B; and so on to other cases.

In the lever of the third kind, (see Fig. 30,) there is power lost; for example, if B F be twice A F, then a weight of 1 cwt. suspended at B will require a power, P, of 2 cwt. applied at A to sustain it.

A poker, as it is usually employed in stirring the fire, is an instance of a lever of the first kind; where the bar of the grate is the fulcrum, and the resistance moved is the coal of the fire. The clawed hammer, as it is used in drawing out a nail, is also a lever of the first kind. The nut-cracker, the oar, &c., are levers of the second kind. The fire tongs, the sugar tongs, &c., belong to levers of the third kind.

Wheel and Axle.

35. This mechanical power is only another form of the lever, where the power is made to act without intermission. In its most simple form, it consists of a horizontal axle, A, (Fig. 32,) and large wheel, R, which turn upon two pivots supported in gudgeons. A cord wrapping round the axle, A, sustains the weight, W, and another cord wrapping round the wheel, R, in a contrary direction, sustains the power, P. These forces always act in the direction of a tangent to the circle. Here the leverage of the power is the radius of the wheel, and the leverage of the weight is the radius of the axle; hence the advantage gained is equal to the number of times that the radius of the axle is contained in the radius of the wheel: thus, if the radius of the wheel is 24 inches, and

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that of the axle 3 inches, then the advantage gained would be 8, and a power of 1 cwt. applied to the wheel would balance a weight of 8 cwt. suspended from the axle.

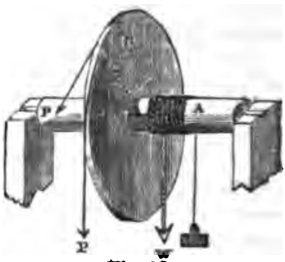


Fig. 32.

36. The windlass is only another form of the wheel and axle, where the handle C B is substituted in the place of the wheel. In this case, the advantage gained is equal to the number of times that the length of handle is greater than the radius of the axle: thus, for example, if the length of the handle is 18 inches, and the radius of the axle is 2 inches, then the advantage would be 9, and a pressure of

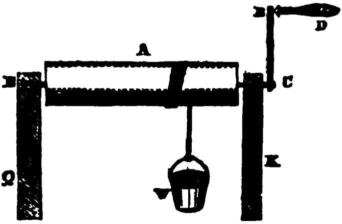


Fig. 33.

60 lbs. applied at the handle would just raise a weight W of 9 times 60 lbs., or 540 lbs.

Combination of Wheels and Axes.

37. In Fig. 34, F is a wheel, to which the power P is applied, and B C its axle, turning upon a common axis; A D another wheel, with its axle E sustaining the weight, W. The motion of the axle B C is transmitted to the wheel A by means of a cord.

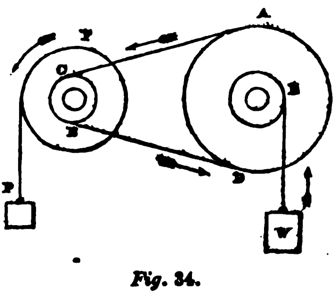


Fig. 34.

To calculate the advantage gained, let the radius of the wheel F be 18 inches, that of its axle B C 2 inches, the radius of the wheel A D 36 inches, and that of its axle E 3 inches; then the advantage gained by the first wheel and axle will be

equal to $18 \div 2 = 9$, so that if P be 1 lb., A will produce a force of 9 lbs. on the cord C A. The advantage gained by the second wheel and axle will be $36 \div 3 = 12$, so that a force of 1 lb. applied to the cord, C A, will sustain a weight W of 12 lbs.; and therefore a weight of 9 lbs. applied to the cord C A will sustain a weight W of 9 times 12 lbs., or 108 lbs.; so that the total advantage gained will be 108.

Cogged Wheels.

38. Let D (Fig. 35) be a *cogged* or *toothed wheel*, turning upon the same axis as the wheel C; Q another cogged wheel, acted upon by the former, and turning upon the same axis as the axle I. From the wheel C, is suspended the power P, and from the axle I, the weight W; then while P descends, the wheel C and the cog D will be turned round, and a corresponding number of teeth in the cog Q will be turned in a contrary direction; and thus the cord I W will be coiled up upon the axle I, and the weight W will be raised.

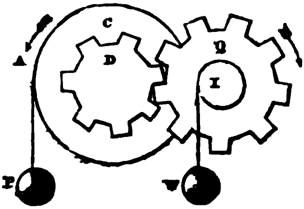


Fig. 35.

When the radii of the wheels and axles are given, the advantage gained by this machine will be found in the same manner as in the foregoing combination.

39. When the axle is placed in a vertical position, and the power is applied by means of bars or levers inserted into the holes at H, as shown in Fig. 36, the machine is called a *capstan*. In this case, the cable coils round the axle in the form of an endless rope, which winds round the lower part of the axle, and at the same time unwinds from the upper part. The axle is made conical, to enable the workman to shift the cable upwards, as it becomes necessary.

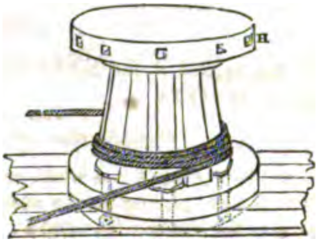


Fig. 36.

40. The *gib crane*, represented in Fig. 36 *a*, is a useful application of the wheel and axle; D O is a vertical beam, resting as well as turning upon a pivot at its under end, and supported in its upright position by stays in the floor, with rollers attached to them; K B is an arm projecting from the beam D O, having a pulley B at its extremity; the axes of the wheel work are supported by two cast iron crosses, bolted on each

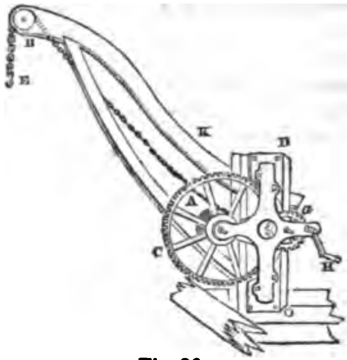


Fig. 36 *a.*

side of the vertical beam; H, the winch or handle, turns a pinion fixed on its axis; this pinion turns the spur wheel *a*, which carries a pinion on its axis; then this latter pinion turns the large wheel C, with its barrel or axle A, round which the chain is coiled; this chain passes over the pulley B, and has a hook at its extremity for laying hold of the weight to be raised; the barrel A has a ratchet wheel and detent to prevent any recoil. As the gib admits of being turned round in any direction, a weight raised from one side of it may be turned round and let down at the opposite side, or at any part within the sweep of the gib. To understand the construction of a crane, you should go and see one at work.

The Pulley.

41. When a rope P A B W passes over a fixed wheel C turning on an axis, the mechanism is called a pulley. A force pulling at the cord P A causes the wheel C to turn upon its axis from the friction of the cord on its edge; and as the wheel turns it gives off cord equal in length to the space described by its circumference.

Fig. 37.

Here the motion of P and W must be equal; for, whatever space P may descend, W will ascend through the same space. Moreover, when equilibrium takes place, the tension or stretch of the single cord P A B W must be the same in every part, and the tension of the portion A P will be the same as the tension of the portion B W; therefore the weight P must be equal to the weight W, in order to produce these equal tensions.

Fig. 38 shows the manner in which a pulley is constructed.

The pulley is said to be *fixed* or *movable*, according as its block is fixed or movable. There are various combinations of pulleys; in all of them a force called the power (P) is applied to the first string, and this sustains another force, called the weight, (W,) applied to the last string.

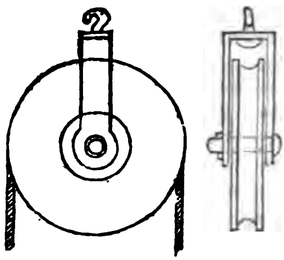
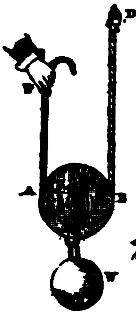


Fig. 38.

In Fig. 39 a continuous cord P A B D passes over a *movable pulley* C, and is fixed to a hook at D. The power is applied at P; and the weight W to be raised is suspended from the block of the pulley. Here, as W is suspended by two cords A P and B D, each cord must sustain one half the weight — that is to say, the power will be one half the weight, or a power of 1 lb. will support a weight W of 2 lbs.



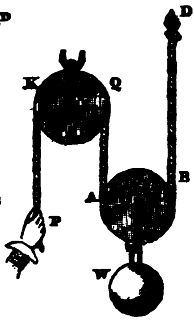


Fig. 39. *Fig.* 40.

In Fig. 40 F is a *fixed pulley*, and C a movable one; the single or continuous cord P K Q A B D passes over the wheels F and C, and is fixed to a hook D. If W, with its pulley C, ascend 1 foot, the cords B D and A Q will each be shortened 1 foot, and therefore the cord K P will be lengthened 2 feet — that is, the velocity of P will be double the velocity of W; and, therefore, on the principle of virtual velocities, the advantage will be 2 — that is to say, 1 lb. suspended at P will sustain 2 lbs. suspended at W.

42. *Principle of Tension.* — The single cord P Q B D will have the same tension in every part; now, W hangs by the two cords B D and A Q; therefore each cord must sustain a weight equal to one half W — that is,

the cord A Q will have a tension of one half W; but this tension is resisted by the power at P; therefore P must also be one half W.

In the annexed system there are two movable pulleys, A and B, and one fixed pulley, C. Here the string to which the power is attached passes over the fixed pulley C, then round the movable pulley A, and has its extremity fixed at T. Another string is attached to the block of the pulley A, then passes round the movable pulley B, and has its extremity fixed at N. Here P Q R A T, being a continuous cord, will be stretched equally throughout the whole of its length; and the cords A R and S T will each have a tension P lbs.; and, therefore, a weight of 2 P lbs. must be suspended from D. In like manner, since D B L N is a continuous cord, L N and B D will have the same tension — that is, each of them will have a tension of 2 P lbs.; and, therefore, a weight of twice 2 P lbs., or 4 P lbs., must be suspended from K; that is to say, in the system represented in Fig. 41, we have W = 4 P.

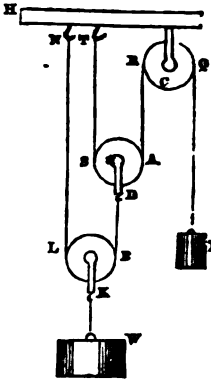


Fig. 41.

In this system, (see Fig. 42,) a single or continuous cord passes round the wheels; therefore every portion of the cord must have the same tension; but W hangs by six cords; therefore each cord will carry one sixth of the weight W, and, consequently, the power P must also be one sixth of W; that is, W = 6 P.

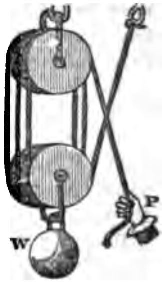


Fig. 42.

By means of a fixed pulley (see Fig. 43) a man may raise himself to any height, or let himself down to any depth. Fire escapes have been constructed on this principle.

43. Pulleys are frequently employed for changing

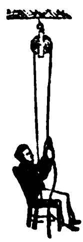


Fig. 43.

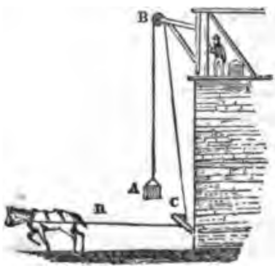


Fig. 44.

the direction of motion. Fig. 44 shows the manner of converting a horizontal motion into a vertical motion. C and B are two fixed pulleys, having a continuous cord H C B A passing over them; A is the weight to be raised by means of a power applied to the horizontal rope C H. In this case there is no mechanical advantage gained.

This figure (45) represents a system of pulleys called the *Spanish barton*. A and C are two movable pulleys, and B is a fixed pulley; P A C G H is a continuous cord passing over the two movable pulleys, having the power P at one extremity, and the other extremity fixed to a hook H; A B D E is another continuous cord passing over the fixed pulley B D, and connecting the blocks of the two movable pulleys A and E. Let P = 1 lb., then the cord P A C G H, being a single cord, the portions P A, A C, and G H will each have a tension of 1 lb.; but the cord A B has a tension of 2 lbs., for it sustains the tensions of A P and A C. Now, A B D E being a single cord, the cord E D has the same tension as the cord A B; that is, E D must sustain a tension of 2 lbs.; but the cords G H and A C have each a tension of 1 lb.; therefore W must be 4 lbs., in order to produce the tensions of G H, E D, and C A. Hence, if P be 1 lb., W must be 4 lbs.

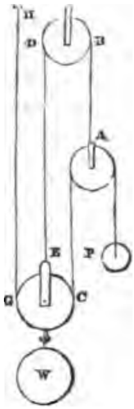


Fig. 45.

The Inclined Plane.

44. When a horse draws a load up a hill, the road forms an inclined plane, and the more gentle the slope the more easily does the horse draw the load. The vertical space through which the weight or load is raised is the vertical elevation of the hill; but the actual space over which the horse draws the load is the inclined side of the hill; therefore the advantage gained by the inclined plane will be the number of times that the length of the plane is greater than its vertical height: thus, if the length of the inclined plane be double its height, then the advantage gained will be 2; that is to say, a weight of 2 cwt. would only require a power of 1 cwt. to draw it up the plane, (supposing that there were no friction.)

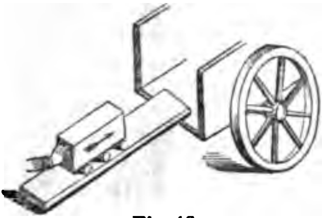


Fig. 46.

Inclined planes are constantly used for rolling casks into carts.

The inclined plane, as a mechani-

cal power, is also frequently used in connection with frictional rollers. In this way workmen are enabled to raise heavy stones into a cart, as shown in Fig. 46. As the rollers are disengaged at the lower end of the stone they are put in at the upper end; so that three or more rollers are kept continually beneath the stone as it is being rolled forward.

Let A C (Fig. 47) represent an incline, A B its horizontal base, B C its vertical height, and B A C its angle of elevation. Let W be the weight placed upon the plane, and P the power of drawing up this weight, by means of the cord P B W passing over the pulley B D, the cord D W, in this case, being parallel to the plane.

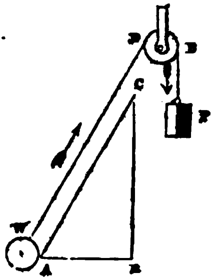


Fig. 47.

To find the ratio of the vertical velocities of P and W. Here, while W moves from A to C, it will have been raised the vertical height, B C, of the plane, and the cord D W being shortened a space equal to A C, P will have descended a space equal to A C, the length of the plane; hence the velocities of P and W, estimated in a vertical direction, will be to each other as the length of the plane to its height; therefore the advantage gained will be equal to the length of the plane divided by its height; that is, $\frac{W}{P}=\frac{A\,C}{B\,C}$. If, for example, A C = 7 feet, and B C = 2 feet, then the advantage gained will be $7 \div 2 = 3\frac{1}{2}$; that is to say, a power P of 1 cwt. will sustain a weight W of $3\frac{1}{2}$ cwt.

The Wedge.

45. This mechanical power is merely a *movable inclined plane.* It is chiefly used in splitting timber, and in splitting rocks in quarries. All sharp-edged tools, such as knives, axes, &c., act upon the principle of the wedge. The power of the wedge depends upon the sharpness of its edge.

Let A B C represent a movable inclined plane, or wedge, sliding along the surface H R by the force of a pressure P applied to the back B C of the wedge in a direction parallel to H R; and let W be a heavy rod resting upon the inclined side A C, and constrained to move in a vertical direction. Here the weight W acts vertically, and the power P horizontally. As the wedge is being pushed forward, the rod D W will be raised; so that, while the wedge has passed over a space equal to its

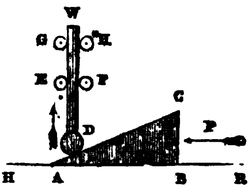


Fig. 48.

length B A, the rod will have been raised through a space equal to the thickness B C of the wedge; that is, while the pressure P has passed over a space equal to A B, the weight W has passed over a space equal to B C; hence the advantage gained will be equal to the number of times that the thickness of the wedge is contained in its length; thus, if the length A B be 9 inches, and the thickness B C $1\frac{1}{2}$ inches, the advantage gained will be $9 \div 1\frac{1}{2} = 6$; that is to say, a pressure of 1 lb. applied to the head of the wedge will produce an upward pressure, in the direction D W, of 6 lbs.

Here Fig. 49 shows the form of the wedge as it is employed in split-

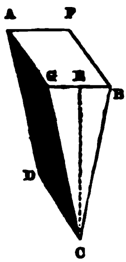


Fig. 49.

Fig. 50.

ting timber, where C E is the length, D C the edge, and G B or A F the thickness. In Fig. 50, the resistance acting at F arises from the adhesion of the material that is being split; and the power applied at A B is the impetus given by the stroke of a heavy mallet. The great power of the wedge, used in this manner, depends almost entirely upon *the work*, accumulated in the mallet, being at once delivered upon the head of the wedge.

The wedge is frequently employed in raising great weights for a short distance; in such cases two wedges are made to act together, as in the annexed figure, where A B *d c* and *d b a c* represent two similar wedges employed for raising the mass W, by simultaneous strokes given to the heads A *c* and *d b*. It is evident that the plane of *a b* will always be parallel to A B.

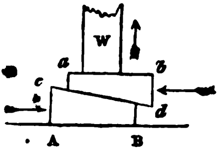


Fig. 51.

The Screw.

46. In this simple machine the power moves in a circle whose radius is the length of the lever, or arm of the screw, whilst the weight or

resistance is moved in a right line having the direction of the axis of the cylinder on which the threads of the screw are formed. A screw may be regarded as a movable inclined plane formed upon the surface of the cylinder; for if we suppose one revolution of the thread to be unwrapped, it will form an inclined plane, in which the circumference of the cylinder will be the length of the plane, and the distance between the threads the height of the plane.

Let *c n a m e* (Fig. 52) be a spiral groove cut upon a cylinder after the

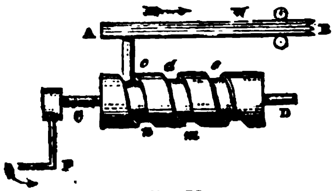


Fig. 52.

manner just described; C D the axis upon which the cylinder turns; A B a rod parallel to the axis C D, and having a pin or tooth, *c*, fitting the groove of the screw. Now, when the handle C P is turned in the direction of the arrow, the pin *c*, with its rod A B, is moved towards the right; so that in one revolution the pin will have moved from *c* to *a*, the distance between the threads of the screw; and in the second revolution it will have moved from *a* to *e*, and so on. The rod A B will thus be moved in a rectilinear path, parallel to the axis C D. In one revolution of the handle, therefore, the power P will have passed over a space equal to the circumference of the circle described by the handle, and the weight or resistance W will have moved over a space equal to the distance between the threads of the screw. Hence the advantage gained will be equal to the circumference of the circle described by the power P divided by the distance between the threads of the screw. Thus, if the circumference described by the handle P C be 20 inches, and the distance *c a* between the threads of the screw $\frac{1}{2}$ inch, then the advantage of pressure gained will be $20 \div \frac{1}{2} = 40$; that is to say, if a pressure of 50 lbs. be applied at P, it will produce a pressure of 40 times 50 lbs., or 2000 lbs., in the direction A B.

In the place of a single tooth, *c*, and the rod, A B, it is customary to have a series of teeth, in the form of a reverse or hollow screw, exactly fitting the spiral groove formed on the cylinder or solid screw C D; the reverse screw thus formed is called the *nut*. In most applications of the screw, the nut revolves, while the solid screw moves in a longitudinal direction.

The Common Press.

47. The screw is used in cases where a great pressure is to be exerted through a small space. The common press is one of the most useful applications of this mechanical power.

Fig. 53 represents a bookbinder's press, where S S is the solid screw working in the hollow screw or nut *n*, resting on the fixed board *c*; B the press board, fixed to the top of the screw, and admits of being moved vertically between the sides of the frame. The solid screw S S is incapable of revolving, but moves longitudinally, or in the direction of its length; whereas the nut *n* revolves, but does not move longitudinally, or in the direction of the length of the screw. The nut is turned by means of the lever P, which is inserted in the holes formed on the edge of the nut. The material to be compressed is placed between the press board B and the fixed beam D.

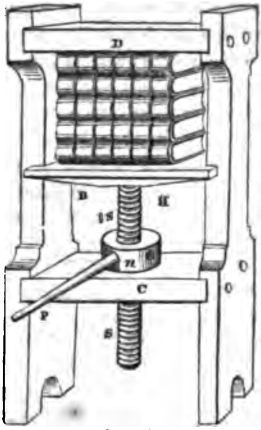


Fig. 53.

In one turn of the lever P, the screw S S, with its press board B, is moved upward a space equal to the distance between the threads of the screw. Hence we have the

$$\text{Advantage gained} = \frac{\text{space described by P}}{\text{distance between the threads.}}$$

Thus, if P sweep a circle of 20 feet, or 240 inches, and the distance between the threads of the screw be $\frac{3}{4}$ of an inch, then the advantage of pressure gained will be $240 \div \frac{3}{4} = 320$; that is, if a man exert a pressure of 56 lbs. upon the extremity of the lever, then the upward pressure produced upon the press board will be 320 times 56 lbs., or 17,920 lbs. = 8 tons.

Wheel Work.

48. Motion may be communicated from one axis to another by means of cords or straps, as in case shown in Fig. 34, or by means of toothed wheels, as shown in Fig. 35. If the toothed wheel B drive the toothed wheel A, (Fig. 54,) then B is called *the driver*, and A *the follower*. Wheels acting in this manner are also called *spur wheels*. Small toothed wheels are called *pinions*; thus B may be called a pinion

in relation to A. Two toothed wheels are said to be *in gear* when their teeth are engaged together, and out of gear when they are separated.

If B contain 15 teeth, and A 90, then B must turn round six times in order that A may turn round once. Or, generally, if A make one revolution, the number that B will make is found by dividing the number of teeth in A by the number in B. Or, since the number of teeth in the wheels is proportional to their radii, the number of revolutions of B will also be found by dividing the radius of A by the radius of B; thus, let the radius of A be 15 in., and that of B 3 in., then B will make five revolutions while A makes one.

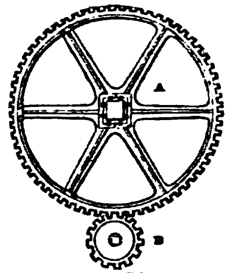


Fig. 54.

In the *train of wheels* represented in Fig. 55, the motion of the axis N_1 S is transmitted to three distinct parallel axes. N_1 is the first driving wheel, n_1 its follower; N_2 is the second driving wheel, n_2 its follower; and so on. Let the number of teeth in $N_1 = 36$, in $n_1 = 9$,

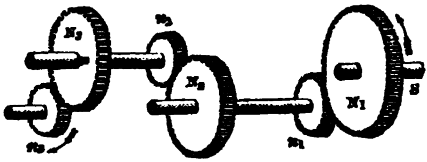


Fig. 55.

in $N_2 = 32$, in $n_2 = 8$, in $N_3 = 35$, and in $n_3 = 7$; then, while the axis of N_1 makes one revolution, the axis of n_3 will make 80. In order to prove this, suppose the driver N_1 to make one revolution, then, while N_1 makes one revolution, the number of revolutions which n_1 will make $= 36 \div 9 = 4$. Now, as N_2 revolves on the same axis as n_1, the driver N_2 will make four revolutions while N makes one. In like manner, N_3 will make four revolutions while N_2 makes one; but N_2 makes four revolutions while N_1 makes one; therefore N_3 must make four times four revolutions, or sixteen revolutions. In like manner, n_3 will make five revolutions while N_3 makes one; but N_3 makes sixteen revolutions while N_1 makes one; therefore n_3 will make sixteen times five revolutions, or eighty revolutions, while N_1 makes one.

When motion is to be transferred from one axis to another axis at right angles to it, we must use crown wheels, bevelled wheels, or face wheels.

Crown Wheels.

49. This figure 56 represents a *crown wheel* B, with its pinion A, having their axes at right angles to each other. The teeth in the crown wheel are cut on the edge of a hoop, and the pinion is made thicker than usual. This kind of wheel is used in clock and watch work.

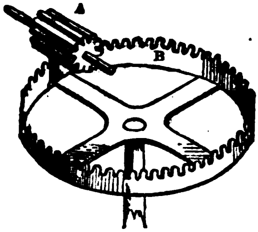


Fig. 56.

Face Wheel and Lantern.

50. In Fig. 57, F represents a *face wheel*, with its *lantern* L. Motion is here transferred from a vertical axis to a horizontal one. The teeth inserted into the face of the wheel F are called *cogs*, which are now usually made of iron, while the round *staves* forming the teeth of the lantern are made of hard wood; for it has been ascertained that iron

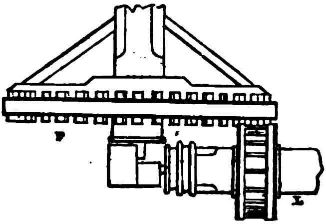


Fig. 57.

cogs work with less noise and friction upon wooden staves, than when the cogs and staves are made of the same material. The face wheel and lantern have been much used in mill work.

Bevel Wheels, or Bevel Gear.

51. Let E B and F B (Fig. 58) be two axes of rotation, cutting each other in B. Two right cones A B C and B D C, touching each other in the line B G C, are formed upon these axes. If the cone B D C revolve on its axis E B, it will communicate, by rolling contact, a rotatory motion to the cone A B C, upon its axis F B.

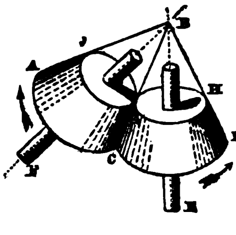


Fig. 58.

In practice, frustra of the cones are employed, as A C G J, and C D H G.

These cones, or frustra of cones, will obviously perform their revolutions in the same manner as the spur wheels in Fig. 54.

On these smooth surfaces of the frustra a series of equidistant teeth may be cut, directed to the apex B of the cone, so that a line passing from the apex B to the outline of the teeth upon the bases of the cones

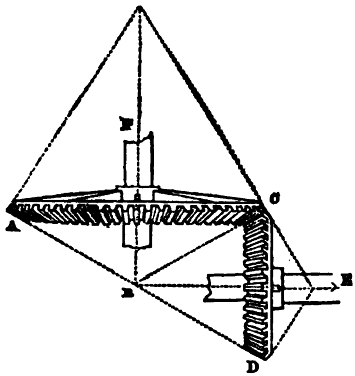


Fig. 59.

shall touch the teeth in every part; as shown in the annexed cut, (Fig. 59,) where B is the apex of the cones B A C and B D C, F and E the two axes of the *bevel wheels* A C and D C, intersecting in the apex B.

Wheels cut in this manner are called *bevel gear*. Two bevel wheels of this kind will always communicate motion from one axis to another, provided these axes intersect each other; this point of intersection is always made the apex of the frustra forming the bevel wheels.

Rack and Pinion.

52. When a circular motion is to be changed into a rectilinear one, the teeth are cut upon the edge of a straight bar, A B, (Fig. 60,) so that they may work with the teeth upon the wheel or pinion P. The toothed bar A B is called a *rack*, and is constrained to move in its rectilinear path by guides or rollers.

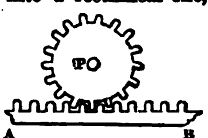


Fig. 60.

53. The way in which a continuous motion is given to a wheel by means of a treadle board is shown in Fig. 61. *c d* is a treadle board, or a board that is moved by the pressure of the foot; the cord *c a e* passes over the pulley *a*, and is attached to the crank *m e* of the wheel *m*. While the extremity *c* of the treadle describes a reciprocating circular motion, the wheel *m* revolves continuously.

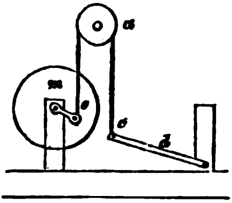


Fig. 61.

54. Fig. 62 shows the way in which a forge hammer is moved by the continuous circular motion of a drum wheel or cylinder. The cylinder *a* (see Fig. 62) has five peculiar shaped teeth upon it, called *wipers* or *tappets*, which strike the extremity of the handle of the hammer at successive intervals. The hammer *b* turns upon a lever *b e*, whose axis is C; the extremity *e* of the lever is depressed by the wipers, and thus the hammer is raised; but the moment the wiper disengages itself from the lever, the hammer falls by its weight, and strikes the heated iron placed upon the anvil A. In this case, the hammer would make five lifts and five strokes for every revolution of the wheel.

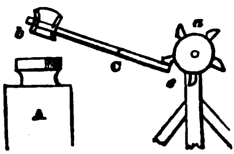


Fig. 62.

In this mechanism, a continuous circular motion is converted into an intermittent reciprocating, or up and down motion.

55. Fig. 63 shows the way in which a continuous circular motion may be converted into a continuous reciprocating, or back and forward

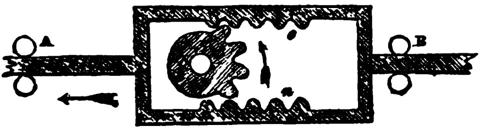


Fig. 63.

motion. *c* is a wheel partially furnished with teeth, acting on two racks, *e* and *n*, placed on different sides of it; the teeth in these racks are alternately engaged by the teeth of the wheel, so that the continuous circular motion of the wheel *c* gives a regular back and forward motion to the rod A B, placed between frictional rollers.

Exercises on Mechanics.

1. A body moves through a space of 540 feet; its velocity is 6 feet per second: what will be the time of its motion? *Ans.* $1\frac{1}{2}$ minutes.

2. A carrier pigeon, flying with a uniform speed of 15 feet per second, was 24 hours in passing from a ship at sea to the land: required the distance in miles. *Ans.* $245\frac{5}{11}$ miles.

3. A ball of 7 lbs. is moving with a velocity of 9 feet per second; and a ball of 3 lbs. moves with a velocity of 14 feet per second: what are their comparative momenta? *Ans.* 3 to 2.

4. A falling body required 7 seconds to reach the ground: through what space did it fall? *Ans.* $788\frac{1}{12}$ feet.

5. One arm of a lever is 44 feet long, and the other is 5 feet: what power applied to the longer arm will balance 500 lbs. at the shorter arm? *Ans.* 56 lbs., $13\frac{1}{11}$ oz.

6. At what distance from the fulcrum of a lever of the second kind that is 20 feet long, must a weight of 112 lbs. be placed, so that it may be sustained by a power of 50 lbs.? *Ans.* 8 feet, $11\frac{1}{7}$ inches.

7. A wheel of 10 feet diameter, with a power of 5 lbs., balances a weight of 150 lbs.; what is the radius of the axle? *Ans.* 2 inches.

THE STEAM ENGINE.

DIFFERENT PIECES OF MECHANISM CONNECTED WITH THE STEAM ENGINE.

1. There are a variety of interesting pieces of mechanism connected with the steam engine, which merit a minute description.

The Crank and Fly Wheel.

2. The crank and connecting rod are used for converting the reciprocating motion of the extremity of the great beam of the steam engine into a continuous circular motion. When we turn a grindstone, we employ the peculiar motion of the crank and connecting rod, where the handle of the grindstone serves the purpose of the crank, and the arm that of the connecting rod. The crank, with its connecting rod and fly wheel, is represented in Fig. 64. C is an axis, to which the fly wheel F, or any other wheel work, may be attached; C D is a link or arm, called the *crank*, fixed to the axis C, and having a joint at D, to which the *connecting rod* D A is attached. Now, if an up and down motion be given to D A, the extremity D of the crank will move in a circle, and thus a continuous rotation will be given to the axis C

When the crank arrives at the position C *n*, where it is in the same line with the connecting rod, it is said to be in one of its dead points, for

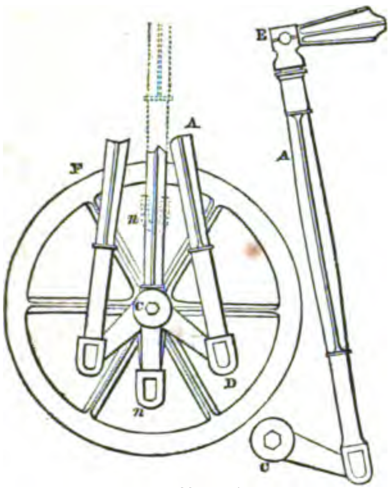


Fig. [illegible]

then the pressure upon the connecting rod has no effect in turning the crank; but in general, the inertia of the machinery and fly wheel F carries the crank beyond the dead points. It will be seen that the crank has to pass over two dead points in the course of one revolution. In order to avoid this irregularity in the action of the connecting rod, two cranks are sometimes placed on the same axis, at right angles to each other. The connecting rod in a steam engine is usually attached to the extremity E of the great beam.

The fly wheel is not only a regulator of motion, but it is also an accumulator of motion. It simply consists of a large, heavy wheel, to which motion is usually given by a crank; thus, in Fig. 64, F is the *fly wheel*, revolving upon the axis C.

The fly wheel may be regarded as a reservoir of motion, in which the redundant motion of the machinery is accumulated when the work to be performed is less than the work applied by the moving power, and from which the machinery derives motion when the work to be performed is greater than the work applied; so that, however variable the work to be performed may be, the motion of the machinery is always maintained pretty nearly uniform.

The Sun-and-planet Wheel.

3. This beautiful contrivance was employed by Watt as a substitute for the crank. It consists of two toothed wheels, one of which revolves round the circumference of the other, somewhat similar to the manner in which a planet and its satellite revolve round the sun; hence the name given to this mechanical combination.

The toothed wheel B (Fig. 65) is fixed to the extremity of the connecting rod C L, so as not to be allowed to turn on its centre; A is another toothed wheel, fixed to the axis *e* of the fly wheel D; a link connects the centres of the two wheels A and B, and serves to keep them in gear. Now, when the great beam has made an up and down stroke, the link *e o*, connecting the centres of the two toothed wheels, will have performed a complete revolution round the centre *e*, exactly as a common crank would do; but as the two wheels A and B are fixed to their respective centres, every portion in the circumference of B will have been brought in contact with the wheel A, which thus receives a continuous

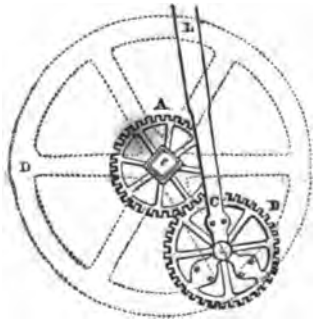


Fig. 65.

circular motion. Assuming the wheels A and B to be equal, then, while the connecting rod makes an up and down stroke, or, what is the same thing, while the wheel B makes one revolution round the centre *e*, the wheel A, with the fly wheel D, will have performed two revolutions; for in this case every tooth in A will have come twice into contact with the teeth on B.

Watt's Parallel Motion.

4. This beautiful mechanical contrivance is used to convert the reciprocating circular motion of the extremity of the great beam of an engine

into the reciprocating rectilinear motion of the piston rod. It consists of a frame of link work somewhat in the form of a parallel ruler.

The leading feature of the contrivance is represented in Fig. 66.

Let A B and C D be two equal rods, connected by the link D B, moving on their respective fixed centres of motion A and C. Let E be

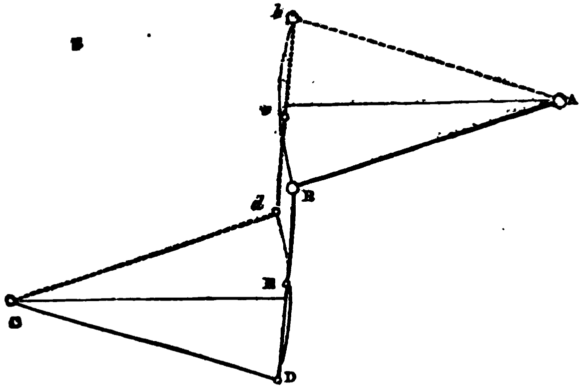


Fig. 66.

the middle point of the connecting link D B. Now, let the rods be moved to another position, and let C *d e b* A be that new position of the rods; then the middle point E or *e* of the link will have nearly moved in a vertical right line. For while, by this motion, the extremity B of the link is carried to the left, the extremity D is carried to the right, and *vice versa*; so that the middle point E of the link thus nearly moves in a vertical line.

Let A K (Fig. 67) represent one half of the great beam, turning on the centre A; K B D R link-work in the form of a parallelogram, having B K equal to A B; C D a rod, called *the radius rod*, turning on the fixed centre C. Now, the rods A B D C will move in precisely the same manner as in the preceding figure, and therefore the point E, in the middle of the link D B, will very nearly describe a vertical line. But since the triangles A R K and A E B are similar, and as A K is the double of A B, the line A R will be the double of A E; that is, the point R will always be at double the distance from A that

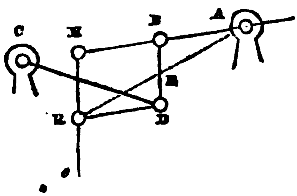


Fig. 67.

the point E is; and therefore the path described by R will be the same as the path described by E; therefore, if the point E moves in a vertical line, the point R will also move in a vertical line. The piston rod is attached to the point R, and the piston rod of the air pump to the point E; so that both of these rods will be moved in a vertical line.

The Eccentric Wheel.

5. A wheel is said to be *eccentric* when it turns on an axis which does not lie in the centre of the wheel. This important piece of mechanism is usually employed to give motion to the slide valve of the steam engine where the axis of the fly wheel is always the centre of motion of the eccentric wheel. Here A is the axis of the eccentric wheel, C being the centre of the circle; a hoop J K embraces the eccentric wheel, so as to allow the wheel to revolve freely within the

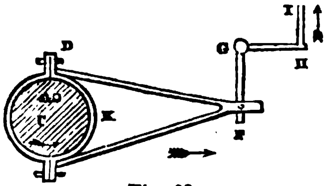


Fig. 68.

hoop; a frame D F E connects this hoop with the extremity F of the bent lever H G F turning on the fixed centre G. Now, when the eccentric wheel turns in the direction of the arrow of the figure, the frame E D F is pushed to the right, and the pin F describes an arc of a circle in the same direction, on G as a centre; when the lob side of the eccentric has passed the line of the centres of motion A and F, the frame with the pin F is then drawn to the left, and so on; so that the continuous circular motion of the eccentric wheel produces a reciprocating circular motion in the pin F. This motion of F gives a reciprocating motion to the rod H I, to which is attached the slide valve of the engine.

The Governor.

6. This is one of the most important regulators of machinery. When the speed of the machinery is too great, this contrivance checks the supply of the moving force; and, on the contrary, when the speed is too slow, it increases that supply. This simple and beautiful piece of mechanism (see Fig. 69) consists of two heavy balls E E, attached to the extremities of the rods *f e* E, which pass through a slit in the vertical

axis D D, and turn on the centre *e*, opening and closing like a pair of shears. The links *f h*, having joints at *f* and *h*, connect the two rods *f e* E with a ring *h h* D, which slides freely upon the vertical axis D D, to which a rotary motion is given by means of a belt passing round the

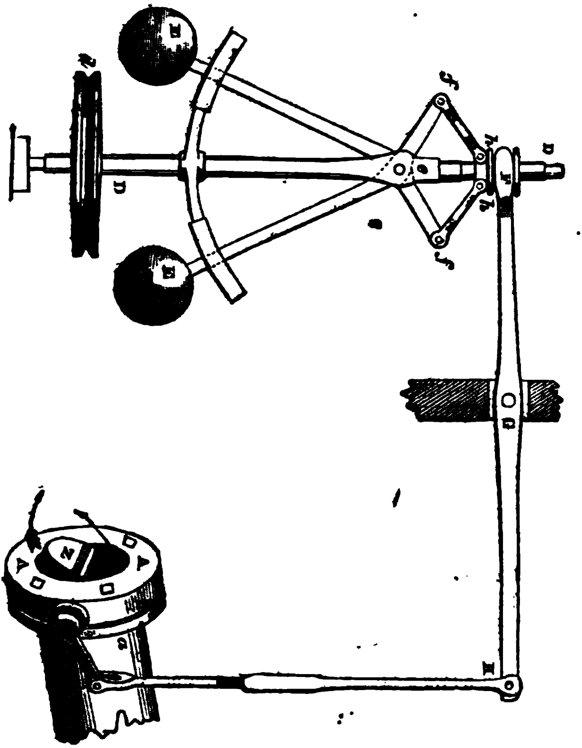


Fig. 69.

pulley *d*. The lever F G H, turning on the centre G, is connected with the sliding piece or ring *h h* D at the extremity F, and has a link H *w* attached to the extremity H. The link H *w* turns the axis of the throttle valve Z, which opens and closes the port of the steam pipe A A *a*, proceeding from the boiler to the cylinder. Now, when the spindle D D revolves with an increasing velocity, the balls E E fly out from the centre of motion, (by the centrifugal force thus generated;) the sliding piece or ring *h h* D, with the extremity F of the lever, is drawn downwards,

while the extremity H is raised, and the axis of *the throttle valve* Z is turned round, so as to close the opening of the steam pipe, thereby reducing the supply of steam. The contrary effect is produced when the velocity of the spindle D D is decreasing; that is, the balls fall towards the axis D D, and the throttle valve Z is turned, so as to increase the supply of steam. Hence it appears that when the speed of the engine passes beyond a certain limit, the throttle valve tends to check the supply of the steam, or moving principle; while, on the contrary, when the speed of the engine is less than this mean limit, the throttle valve is opened, so as to allow a greater quantity of steam to pass through the steam pipe.

THE STEAM BOILER AND ITS APPENDAGES.

7. 'The steam boiler is made of thick sheet iron or copper plates, riveted strongly together to resist the expansive pressure of the steam as well as the destructive action of the great heat which is applied to them. Steam boilers are made of various forms.' Fig. 70 represents a

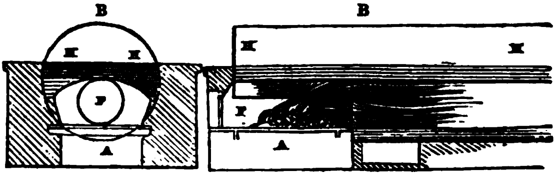


Fig. 70.

longitudinal as well as a cross section of what is called the butterly boiler, which is much used in our manufacturing districts; A represents the ash pit, F F the furnace, B the boiler, and H H the level of the water in the boiler. The concave form given to the bottom of the boiler obviously brings a larger extent of surface in contact with the flame than would take place if the bottom were flat.

The steam boiler has various appendages, which require special notice.

The Safety Valve.

8. The safety valve is used to secure the boiler from bursting by the excessive pressure of the steam. Fig. 71 represents *the lever safety valve*, where A B is the lever with its load L, pressing upon the head of the valve V, which closes the opening S leading into the boiler. By sliding the load L along the lever, any pressure may be put upon

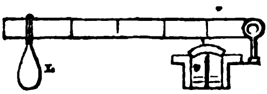


Fig. 71.

the valve that may be found necessary to work the engine. The divisions upon the lever enable the engineer to determine the elasticity of the steam in the boiler.

The Steam Gauge.

9. This instrument is designed to indicate the degree of pressure of the steam which is used in working the engine. Fig. 72 represents a mercurial steam gauge; A C D E is a bent tube, open at both extremities, passing from the vessel B containing the steam; G is a graduated scale for indicating the height of the mercury in the leg D E. When the pressure of the steam is equal to that of the external air, the mercury in the two legs C D and D E stands at the same level, H R; but when the pressure of the steam is greater than the external air, the mercury is depressed in the leg C D and elevated in the leg D E. The excess of pressure of the steam above that of the atmosphere is found by observing the difference of the levels of the mercury in the legs D E and D C, and then allowing half a pound as the pressure of the steam on

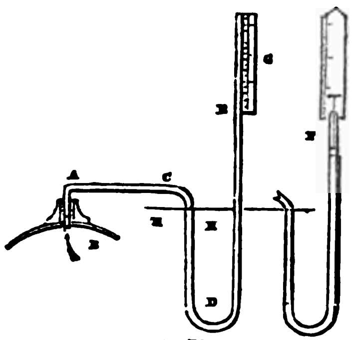


Fig. 72.

each square inch for every inch in the difference of the levels. The bent tube is frequently made of iron. In this case a float F, with a rod and pointer, is inserted into the open end of the tube. As the float F is raised or depressed with the mercury, the pointer is made to indicate the difference of the levels of the mercury in the two legs of the instrument.

The Water Gauge.

10. This simply consists of a bent glass tube A D C B, (Fig. 73,) where one extremity A enters the boiler above the proper level H R of the water, and the other extremity B enters below the proper level. As the water must stand at the same level in the glass tube D C that it does in the boiler, the eye of the engineer will at once see what depth of water is in the boiler. Another kind of water gauge is explained in the general description of the steam engine.

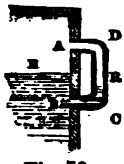


Fig. 73.

The Water Regulator.

11. In the steam engine it is especially necessary that the water in the boiler should be constantly kept at the same level, so that as the water is being evaporated in the boiler fresh water should at the same time be admitted to supply the waste thus created. Fig. 74 represents a portion of the boiler A, with A B a pipe proceeding from the cistern B to supply the boiler with water as it may be required; F is a stone float suspended by the rod F C passing through the stuffing box S; this rod is attached to the extremity C of the lever C F turning upon the fulcrum or centre D; V is a valve opening and closing the top of the pipe A B, and attached to the point E of the lever C F; F is a counterpoise which aids in depressing the valve V. Now, when the water in the boiler descends below its proper level, the float F also descends, and by depressing the extremity C of the lever elevates the valve V, and thus allows the water to flow into the boiler as required. On the contrary, as the water rises in the boiler the float F also rises, and by elevating the extremity C of the lever depresses the valve V, and thus stops the flow of water into the boiler; thus a certain mean quantity of water is always maintained in the boiler.

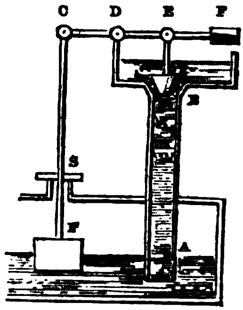


Fig. 74.

The Self-regulating Damper.

12. The rate at which steam is generated in the boiler should be equal to the rate at which it is consumed in the cylinder; or, what is the same thing, the steam in the boiler should be maintained at a constant pressure. In order to effect this, some connection must be formed between

the pressure of the steam in the boiler and the heat of the furnace, since the pressure of the one depends upon the heat of the other. This has been accomplished by the following contrivance: Fig. 75, B A is a tube descending nearly to the bottom of the boiler A; F is a float suspended by a chain P Q D passing over the pulleys P and Q; D is a damper acting as a counterpoise to the float, and opening or closing, as the case may be, the mouth of the flue L, and thereby increasing or decreasing the draught of air through the fire K. Now, the level F of the water in the tube A B depends upon the pressure of the steam in the boiler A; but the float F rises and falls with the water in the tube A B, and as the float rises the damper D descends, and *vice versa;* so that, when the pressure of the steam in the boiler exceeds its proper limit, the water in the tube A B, together with the float F, ascends, and then the damper D descends and closes the mouth of the flue, thereby reducing the intensity of the heat of the furnace, and checking the further generation of steam. On the contrary, when the pressure of the steam falls below its proper limit, the water in the tube, with the float, descends, the damper D is raised, and an increase of draught is given to the furnace, which produces a more rapid generation of steam, and consequently with an increase to its pressure.

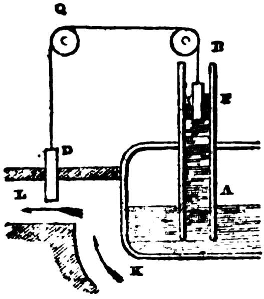


Fig. 75.

DIFFERENT FORMS OF THE STEAM ENGINE.

Hiero Engine.

1. The first steam engine was invented by Hiero of Alexandria, 120 B.C. It now forms one of our prettiest philosophical toys. This engine is represented in Fig. 76: A is a hollow globe containing water, turning on a vertical axis *a; a b,* &c., are four horizontal tubes having their exterior orifice bent in the same direction as in Barker's mill. When the water boils, steam issues from these orifices, and causes the globe to rotate upon its axis.

Fig. 76.

Savery's Engine.

2. This engine was used for raising water from deep mines. The principle on which it acts may be explained as follows: Fig. 77, C is a large cylindrical vessel, called *the receiver*, into which steam enters by *the steam pipe* S, communicating with a strong boiler, called *the steam boiler*, where steam at a high pressure is generated; the steam pipe S has a cock *a*, called *the steam cock*, which opens and closes the communication of the receiver with the steam boiler; I is *the injection pipe*, which conveys a jet of cold water into the interior of the receiver for the purpose of condensing the steam; this pipe has also a cock *b*, called *the injection cock;* these two cocks *a* and *b* are turned by the same handle A, so that when *b* is open *a* is closed, and *vice versa;* F is a pipe descending into the water which is to be raised; at the top of this pipe is the valve V, lifting upwards; E D is a pipe proceeding from the bottom of the receiver to the cistern, into which the water is to be discharged; in this pipe is placed the valve *v*, lifting upwards.

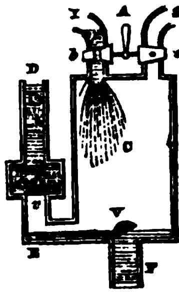


Fig. 77.

To work the engine, the steam cock *a* is opened and *b* is shut; then the steam, rushing along the steam pipe S, enters the receiver C, and drives the air out of it through the valve *v*. When the receiver is filled with steam, the steam cock *a* is closed, and at the same time the injection cock *b* is opened; then the jet of cold water proceeding from the injection pipe instantly condenses the steam in the receiver, and a vacuum is formed. The pressure of the atmosphere on the surface of the water in the well or pit forces the water up the pipe F, and nearly fills the receiver. The engineer now lays hold of the handle A and opens the steam cock *a*, at the same time that he closes the injection cock *b*. The steam again enters the receiver, and by its great elastic pressure exerted upon the surface of the water forces the water through the valve *v*, up the pipe E D, to the top of the pit or mine. In the same manner the engine is made to perform any number of strokes.

The defects of this engine are as follows: 1. It is limited in its application to the raising of water; 2. There is a great loss of power at each successive lift, occasioned by the steam coming in contact with the cold water in the receiver.

Newcomen's Engine with the Crank and Fly Wheel.

3. This engine was a great improvement upon Savery's. Its leading features are represented in Fig. 78. C is the boiler, communicating with the cylinder E by means of the steam pipe S; P is the piston rod, con-

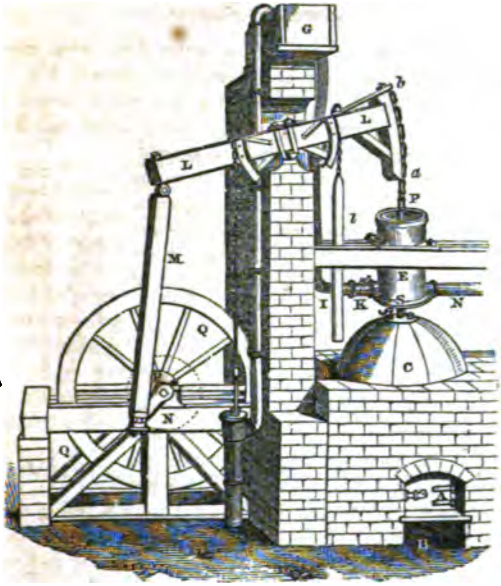


Fig. 78.

nected with a solid piston, which works steam tight in this cylinder; the rod P of the piston is connected with the chain which coils round the arched head *a b* of the great beam L L; so that as the piston descends the extremity of the great beam is drawn down, and at the same time the piston rod does not deviate from its vertical position; G is a cistern of cold water called *the injection cistern;* from this descends the injection pipe G I K, (see also Fig. 79,) which enters the bottom of the cylinder: K is *the injection cock;* at the opposite side of the cylinder there is a lateral pipe, turning upwards at the extremity, having a valve N, called *the snifting valve,* lifting upwards: Q is *the eduction pipe,* for drawing off the water formed in the cylinder; the extremity D of this pipe is inserted in a vessel of water, and has its orifice closed by a valve lifting outwards.

When the engine is required to be put in action, — let us suppose that the piston P is drawn to the top of the cylinder, — the steam

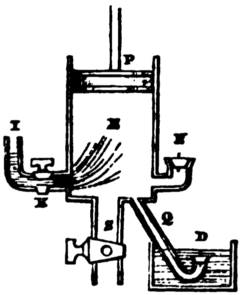


Fig. 79.

cock S is opened, and the injection cock K is closed; then the steam, having a pressure a little above that of the atmosphere, flows from the boiler into the cylinder, and drives out the air through the snifting valve N. When the cylinder is completely filled with steam, the steam cock S is closed, and the injection cock K is opened; then a jet of cold water is thrown into the cylinder, which instantly condenses the steam; a vacuum being thus formed, the pressure of the atmosphere upon the top of the piston causes it to descend. When the piston has arrived at the bottom of the cylinder, the steam cock S is again opened, and the injection cock K closed; then the steam again enters the cylinder, blows out, as before, any air that may have got in, and forces the water formed in the cylinder by the condensation of the steam down the eduction pipe Q; this water escapes by the valve D into the cistern; the steam beneath the piston now balances the pressure of the external air, and a counterpoise at the opposite end of the great beam raises the piston in the cylinder. But in the engine represented by Fig. 78 this is effected by the momentum of the fly wheel Q Q. In the same manner any number of strokes are performed.

In this engine the pressure of the atmosphere is the moving power, the steam being merely employed to form the vacuum beneath the piston. With the crank and fly wheel this engine was employed as a prime mover of machinery generally, and the whole of its parts were made self-acting by Beighton and Smeaton. Its defects are as follows: 1. The want of uniformity in the action of the moving power; 2. The loss of power, at every upward stroke of the piston, from the condensation of steam by the cold cylinder; for it will be observed that at every downward stroke the cylinder had to be cooled down by the injection water. These defects are completely remedied in Watt's double-acting engines, by introducing a separate vessel, called the condenser, where the steam is condensed, and by using the steam not merely to form a vacuum, but also to move the piston up and down by its elastic pressure.

Watt's Engine.

4. The first engine constructed by Watt was what is called the atmospheric engine, which only differed in principle from Newcomen's by having the steam condensed in a vessel separate from the cylinder. He afterwards employed the steam to produce an upward as well as a downward stroke, and from this circumstance the engine has been called the double-acting condensing engine. This new principle required that the piston rod should be connected with the extremity of the great beam in such a manner that the motion of the piston should be communicated to the beam in both directions of the stroke. This led to the invention of

the parallel motion described at page 55 of this work. Various other mechanical artifices were also introduced by him, to render the machine perfect in all its parts; such as the contrivances for lifting the valves so as to distribute the steam above and below the piston.

HIGH AND LOW PRESSURE ENGINES.

Steam engines are of two kinds — the *high pressure* or non-condensing engine, and the *low pressure* or condensing engine. In the *high pressure engine*, after the steam has been admitted to the cylinder to press on one side of the piston, forcing it up or down according as it enters from below or above, it escapes by a tube into the open air. The resistance of the atmosphere to the issue of the steam diminishes the working force of the piston. In the *low pressure engine*, the escape pipe, instead of opening into the air, is conducted into a vessel called the *condenser*, into which cold water is constantly running to condense the steam. Hence, as the interior of the low pressure engine is kept in a state of *vacuum*, except where the steam is acting, there is no loss of power by atmospheric resistance; and consequently a [illegible]er pressure of steam is required to produce an effect equal to that of the high pressure engine.

As all the condensing apparatus is dispensed with in the high pressure engine, it occupies less space, is much less complicated, and is therefore used on railroads for locomotives.

VALVES FOR REGULATING THE DISTRIBUTION OF THE STEAM THROUGH THE CYLINDER.

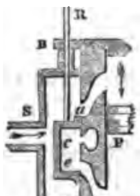
5. There are various contrivances now in use for regulating the distribution of the steam. In the engines constructed by Watt, the valves were opened and closed by means of pins, or tappets, fixed to an oscillating rod, called the plug tree, attached to the great beam of the engine. In engines of moderate power, much more simple contrivances have been adopted, such as the slide valve, the D valve, and the four-way cock.

Slide Valves, &c.

6. *Locomotive Engine, with the common Slide Valve.* Fig. 81 represents the common slide, with its relation to the other parts of the engine, as commonly used in our locomotives. Here P is the piston, moving in the cylinder C, which in a locomotive engine lies in a horizontal position; C D is the piston rod passing through the stuffing box K; D E is the connecting rod, being connected with the piston rod by a joint at D; E F is the crank attached to the axle F of the driving wheel of the carriage. The effect of this mechanical arrangement is, that whilst the

piston moves backwards and forwards in the cylinder, the connecting rod and crank transmit this motion, so as to give a rotatory motion to the axle of the driving wheels, which moves the carriage forward on the rail. We have now to consider a distinct piece of mechanism for moving the slide valve up and down in the *steam box* A B, so as to regulate the distribution of the steam in its passage into the cylinder. The motion of the slide valve must be so adjusted that when the piston is ascending, the steam must be entering the under part of the cylinder, while the steam above the piston is allowed to escape into the atmosphere, as in the case of a high pressure engine, or allowed to pass into the condenser in a condensing engine; on the contrary, when the piston is descending, the steam must be entering the upper part of the cylinder, while the steam below the piston is allowed to escape into the atmosphere,





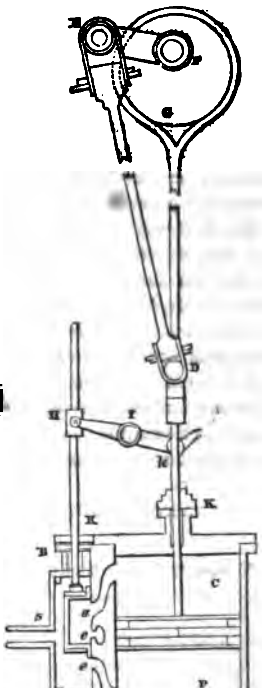


Fig. 83. *Fig.* 84. *Fig.* 82. *Fig.* 81.

or the condenser, as the case may be. In Fig. 81 A B is *the steam box*, which is kept constantly filled with steam by the steam pipe S, proceeding from the boiler; *the slide valve* is moved up and down by the rod R H passing through a stuffing box R; *a* is the upper steam port or orifice leading into the top of the cylinder, and *e* is the lower steam port; exactly between these ports is an opening *c*, which conducts the steam into the condenser, or the atmosphere, as the case may be; G is an eccentric wheel, which turns upon the axle F as a centre of motion; G *k* is the eccentric rod attached to the extremity of the lever *k* H, turning on the fixed centre I; the extremity H of this lever is attached to the rod of

the slide valve, so that when the piston P is ascending, the slide valve is descending, and *vice versa*. *The slide valve* is a piece of metal hollowed on one face, and made to connect two of the openings, *a c e*, on the side of the cylinder, at one time. Fig. 84 shows a separate longitudinal section of the valve, and Fig. 83 shows a view of its hollowed face. This face lies flat against the side of the cylinder, so that the steam, in the steam box, cannot pass beneath the face of the valve.

In Fig. 81 the piston P is supposed to be ascending, and the steam is passing through the lower port *e* into the under part of the cylinder, at the same time the steam is passing from the upper part of the cylinder through the upper port *a*, and is discharged through the centre port *c*. When the piston has performed an upward stroke, and begins to descend, as in Fig. 82, the valve has made a downward stroke, and now connects the lower steam port *e* with the centre port *c*, leaving the upper port *a* open for the steam to enter the upper part of the cylinder; and so on to any number of strokes.

In practice it is customary to have the motion of the valve so adjusted that the steam port may be slightly open when the piston has completed its stroke. The small space thus open is called the lead of the valve. This lead allows time for the steam to enter the cylinder, so as to prepare for the succeeding stroke of the piston.

The D *Valve.*

7. Figs. 87 and 88 represent sections of this valve at different positions of the piston.

Fig. 85 represents a longitudinal section of the valve itself. O is the valve rod working through the stuffing box; E is an opening passing through the valve, of which a transverse or cross section is shown in Fig. 86; S is the hollow in the valve through which the steam passes to the top or bottom of the cylinder, as the case may be; *a b*, in Fig. 86, is the packing at the back of the valve, which works steamtight against the valve box. This is called the D valve, from the form of the cross section, shown in Fig. 86.

Fig. 85.

Fig. 86.

In the position of the valve shown in Fig. 88, the steam passing through the hollow of the valve enters the lower part of the cylinder through the port D, while at the same time the steam in the upper part of the cylinder escapes through the port F, and, descending through the longitudinal opening E in the valve, enters the eduction pipe *c* leading to the condenser. Fig. 87 represents an intermediate position of the valve. The valve is moved by an eccentric, precisely in the same manner as described at page 56.

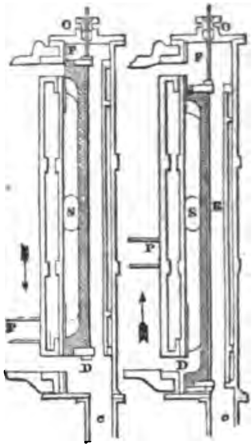


Fig. 87. *Fig.* 88.

The Four-way Cock.

8. Figs. 89 and 90 represent this simple mode of distributing the steam. S, B, C, T are four tubes; S communicates with the steam

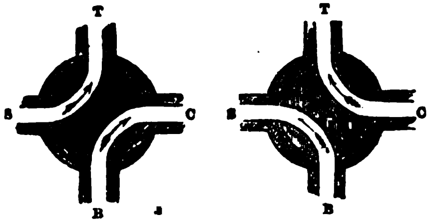


Fig. 89. *Fig.* 90.

pipe proceeding from the boiler; C leads into the condenser, or to the external air, according as the engine is a condensing or a high pressure one; B leads to the bottom of the cylinder, and T to the top of it. These four tubes enter a cock which has two curved passages leading through it, as shown in the figures. These passages are cut in such a manner that by turning the cock they may be made to open a communication between any two adjacent tubes. In the position of the cock shown in Fig. 90, the steam is passing through the tube B to the bottom

of the cylinder; at the same time the steam is passing from the top of the cylinder, through the tube T, into the tube C leading to the con-

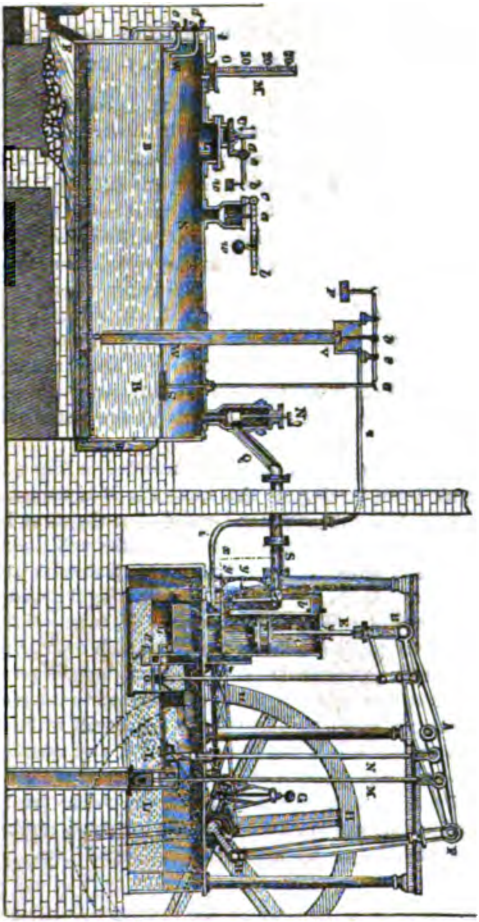


Fig. 91.

Fig. 92.

denser. In Fig. 89 the cock has performed a quarter of a revolution: the steam is now passing through the tube T to the top of the cylinder; at the same time the steam is passing from the bottom of the cylinder

through the tube B, into the tube C leading to the condenser. The eccentric is usually employed to move the cock after the manner described.

GENERAL VIEW OF A DOUBLE-ACTING CONDENSING ENGINE, WITH THE FOUR-WAY COCK.

9. *The steam boiler* and its appendages are represented in Fig. 91. Here F is the furnace; B B the water in the boiler; W W the space occupied by the steam; Q is the steam pipe which conducts the steam to the cylinder; *e a b w* the safety valve, (see page 58;) O V the pipe of the water regulator, S being the float, &c., (see page 59;) *i* a pipe, proceeding from the hot water well, which supplies the boiler with water; *c* and *c'* are the water gauges; the former, *c*, is called *the water cock*, because it communicates with the water in the boiler, whereas *c'* is called the *steam cock*, because it communicates with the steam in the boiler. When the water in the boiler stands at a proper level, upon opening the two cocks, water will issue from the water cock *c*, and steam from the steam cock *c'*; but if the boiler contains too little water, the steam will issue from both cocks; *t t* is another form of the water gauge, (see page 60.)

The engine, with its various parts, is represented in Fig. 92. Here B F is the great beam turning on the centre A; B K the parallel motion, (see page 55;) E P the piston rod, attached to the piston P; C the cylinder; S the steam pipe transmitting steam through the four-way cock to the top and bottom of the cylinder, as explained at page 68; J is the condenser, and O the air pump, surrounded by the cold water in the cold water well L L; W is the hot water well, from which water is pumped through the pipe *i i* to the reservoir V, which supplies the boiler with hot water as it is required; N, the rod working this pump, is attached to the great beam; M is another rod, attached to the great beam, working the pump S, which supplies the cold water well with a constant stream of cold water; F R is the connecting rod and crank, giving a rotatory motion to the fly wheel H H, (see page 53;) the eccentric, fixed to the axle of the crank, as shown in the figure, works the four-way cock, as explained at page 56, &c.; G is the governor, regulating the supply of steam to the cylinder, as explained at page 57, &c.

HYDROSTATICS AND HYDRAULICS.

1. **Hydrostatics** is that part of Natural Philosophy which treats of the weight and pressure of liquids in a state of rest; and **Hydraulics** treats of liquids in a state of motion.

2. *Fluid bodies* differ from solids in readily yielding to any pressure applied to them, and in their tendency to *flow* through any channel. Solids tend towards the earth in masses or lumps; whereas every particle composing a fluid is separately acted upon by the force of gravity. This peculiar property of fluids depends upon the very slight force of cohesion subsisting between their particles, which allows them to have a free motion amongst themselves. Water and air are the most familiar examples of fluid bodies.

3. Substances differ very much in their degree of fluidity, or *tendency* to flow; thus, water and spirits are more fluid than oil or tar, and airs or gases have a higher degree of fluidity than water. *Liquids*, such as water, may be poured from one vessel to another; but airs or gases are so elastic, that they cannot be kept in open vessels. Thus the particles of liquids are held together by a slight force of cohesion; whereas the particles of airs repel each other, or have a tendency to fly away from each other. The little globules of dew often seen on the leaves of plants show that the particles of water have a greater attraction for each other than they have for the leaf. A dry needle, gently placed upon the surface of still water, will float, in consequence of its weight not being sufficient to break the cohesion of the fluid particles on the surface.

4. Moreover, whilst gases admit of being reduced in bulk by a force of compression, liquids can scarcely be compressed at all. Thus, let us suppose that P is a piston, or plug, exactly fitting the smooth face of a cylinder A B C D, and first let the space A B C D beneath the piston be filled with common air; then a force of pressure applied to the handle will cause the piston to descend, and thereby to compress the air beneath it; but the instant this pressure is withdrawn, the air, by its elasticity, raises the piston, and regains its original bulk; hence, air is called an elastic fluid. Again, let the space A B C D beneath the piston be filled with water; then, however great the pressure applied to the handle may be, the water beneath the piston

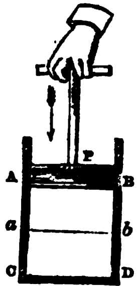


Fig. 1.

will not be sensibly altered in its bulk. Hence, water and other liquids are called non-elastic * fluids.

5. Three laws obtain in reference to fluid bodies:—

First. The surface of still water is always horizontal or level. *Second.* Fluids transmit pressure equally in all directions. *Third.* The pressure of water is in proportion to its depth.

6. The surface of still water is always level.

Whatever may be the shape of a mass of water, its surface, at all parts, will stand at the same level or height. Thus, in Fig. 2, A represents a vessel containing water, *a c* a bent pipe proceeding from the lower part of this vessel; now, the water in A and the water in *a*, having a communication with each other, stand at the same level, *h z*. In the common teapot, the liquid in the pot will always be at the same level with that which is in the spout. Workmen express this property by saying that "water always finds its level." On this principle, pipes are used to convey water from one place to another, however uneven the surface of the ground between the places

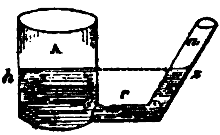


Fig. 2.

Fig. 3.

may be. Towns and cities are thus supplied with water from distant springs. In Fig. 3, S represents a spring or fountain, A B C a pipe conveying water from it to a house; now, although this pipe may rise

* This is not strictly true, because, under a pressure of 15 lbs. per square inch, water is reduced about the 22,000th part of its bulk; however, for all ordinary pressures, water may be practically regarded as non-elastic.

over hills, or pass through valleys, yet *so long as it does not rise above the level of the fountain head*, the water will continue to flow. On this principle the city of Philadelphia is supplied with water from Fairmount reservoir, New York from the Croton River, and Boston from the Cochituate Lake. On this principle, also, little streams descend from the hills to the plains, and mighty rivers flow on towards the ocean.

Levelling.

7. The heights of mountains, as given in geography, are always estimated from the level of the ocean. If the earth were an exact sphere, which it is very nearly, the surface of the ocean would be every where at the same distance from the earth's centre. The surface of a large extent of water is consequently convex; but for any small extent of water, the surface is practically flat. A *spirit level* is the instrument which is usually employed for finding the difference of levels between two places. It consists of a glass tube E F, filled with spirits of wine, excepting a small part B, called the air bubble. This bubble always rises to the higher end of the tube; but when the tube is perfectly level, the bubble stands at the middle, B. In using this instru-

Fig. 4.

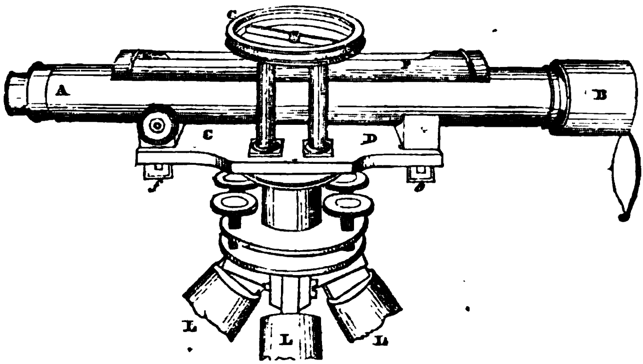


Fig. 5.

ment for ordinary purposes, such as finding the levels for buildings, or drains, it is fixed in a frame with sights placed over the direction of the tube; but when levels are to be taken for great distances, such as occur

in the construction of railways, the instrument is fixed upon the top of a spy glass, or telescope, mounted on a tripod stand, as in the accompanying figure, where E F is the spirit level; A B the spy glass fixed in the horizontal plate C D; screws are placed below this plate for adjusting the spirit level; L L L are portions of the legs on which the instrument stands; the spy glass, with the spirit level, turns round on a vertical axis, so that the person using the instrument can direct the spy glass towards any object. It will be observed that the line of vision through the spy glass is a level line, for it is exactly parallel to the level line formed by the spirit level. In order to show the manner of using this instrument, let it be required to ascertain whether there is a proper descent for water from a well at F to a village at B: place the spirit level D on the eminence E, from which levelling staves F and G B can be seen; adjust the level, and direct the spy glass to the staff F; turn the spy glass upon its vertical axis, and direct it to the staff G B; then the difference between the heights of the staves G B and F will give the descent of the water from the well to the place B.

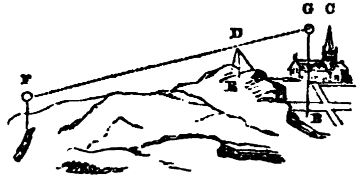


Fig. 6.

8. The line which is determined by the spirit level is a tangent to the earth's surface; in taking levels, therefore, in this manner for any great distance, an allowance must be made for the convexity of the earth; this allowance is about 8 inches for a mile. In Fig. 7, D A C represents a portion of the earth's surface, or the form which the water of the ocean assumes; A B is *the apparent level* taken from A, or the line determined by the spirit level; A C is *the true level*, or the surface which water extending from A to C would assume; B C is the *correction*, or the difference between the apparent level and the true level, which is about 8 inches, when the distance A C is one mile.

Fig. 7.

9. Fluids transmit pressure equally in all directions.

In order to exemplify this principle, let us suppose a bladder to be filled with water, and after the mouth is closed, let it be squeezed or pressed with a force nearly sufficient to burst it; now, every particle of the water will undergo the same amount of pressure, and every part of the bladder will be pressed upon by the water with the same force.

10. In the syringe, Fig. 8, the piston or plug P is forced down upon the water beneath it, and the pressure thus produced is transmitted equally through the whole body of the fluid; hence it is that the water is driven out at the orifice O with a force corresponding to the pressure applied to the piston.

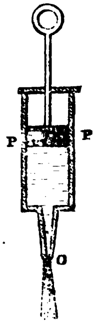


Fig. 8.

11. The principle of the hydrostatic press depends upon this property of fluids: In Fig. 9, A and *a* are two cylinders containing water, connected by a pipe; P is a piston fitting the large cylinder, and *p* another piston fitting the small one. Now, any pressure applied to the small piston will be transmitted by the water to the large piston, so that every portion of surface in the large piston P will be pressed upwards with the same force that an equal portion of surface in the small piston *p* is pressed downwards. For example, let *p* contain one inch of surface, and let the downward pressure applied to it be 20 lbs.; then every inch of surface in P will be pressed upwards with the force of 20 lbs., and therefore as many times as the surface of the large piston is greater than that of the small one, just so many times will the upward pressure upon the large piston be greater than the downward pressure upon the small one; thus if P contain a surface of 30 inches, then the pressure upon it will be equal to 30 times 20 lbs. or 600 lbs.

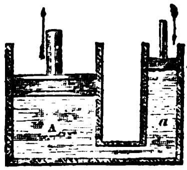


Fig. 9.

12. The pressure of water is in proportion to its depth.

As all the particles of a fluid press on those immediately below them, the particles at any given depth will have to sustain the weight or pressure of those which lie above them. Thus, Fig. 10, the particles at the bottom I J of a vessel filled with water will sustain double the pressure of those lying in the middle E F; and the particles at this depth will sustain double the pressure of those lying in C D at one fourth the whole depth; and so on; hence the pressure of water at any depth is in proportion to that depth. But as water transmits pressure equally in all directions, this pressure will act sideways as well as downwards. Hence the pressure at the points A, C, E, G, and K will be as the numbers 0, 1, 2, 3, and 4 — that is, as the depths. Let holes be bored of the same size at the points D, F, H, J, and K; then the water will flow out at these

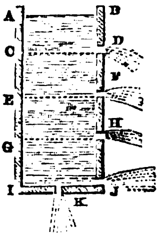


Fig. 10.

holes with forces proportioned to the pressure of the water at these points — that is, with forces in proportion to the depth of the holes below the surface A B of the water: thus the water will flow from K and J with the same force; from F it will flow with half the force that it does from K or J; from D it will flow with one fourth the force that it does from J; and so on.

Pressure on the Bottom of Vessels.

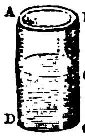


Fig. 11.

13. In upright vessels, the pressure on the bottom is obviously equal to the weight of the water: thus, in Fig. 11, the pressure on the bottom D C is equal to the weight of the water F G C D contained in the vessel; hence *the pressure upon the bottom of a vessel is found by multiplying together the area of the base, the perpendicular depth of the water, and the weight of a cubic foot of water.*

An example will render the truth of this rule more apparent.

Example. Let the area of the base D C contain two square feet, and let the depth of the water G C be three feet; required the pressure on the bottom of the vessel, the weight of a cubic foot of water being 1000 oz.

Content of water = area base $\times$ perpendicular height.
$= 2 \times 3 = 6$ cubic feet.

Weight of water, or pressure on base, $= 6 \times 1000 = 6000$ oz.

14. The pressure on the bottom of a vessel, whatever may be its form, depends solely upon the area of the base and the perpendicular depth of the water. This arises from the law of equal distribution of pressure explained in Art. 9.

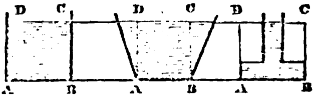


Fig. 12. 13. 14.

Figs. 12, 13, and 14, represent three different vessels having equal bases and the same perpendicular depth of water in them; all their bases will sustain the same amount of pressure. Hence the pressure on the bottom of a vessel containing water is equal to the weight of a column of water whose base is equal to the bottom of the vessel, and its height equal to the depth of the bottom from the surface of the water: thus in the three forms of vessels represented in the foregoing cut the pressure on the bottom is, in all the cases, equal to the weight of the column of water A B C D.

Upward Pressure of Water.

15. The upward pressure of water is very clearly proved by the following simple experiments: —

EXPERIMENTS.

Exp. 1. Tie a piece of bladder B (Fig. 15) to one end of an open tube A B; pour water into it; then, owing to the pressure of this water, the bladder becomes convex; dip the tube into a vessel of water; as the tube is depressed the bladder becomes less and less convex, and it becomes perfectly flat when the water in the tube is on a level with the water in the vessel, for then the upward pressure of the latter is equal to the downward pressure of the former; when the tube is plunged deeper than this, the bladder becomes concave.

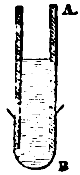


Fig. 15.

Exp. 2. In Fig. 16, A B is a thick tube having its under end ground straight; *n* is a flat piece of lead having a string *n* H attached to it, so that the plate of lead may be drawn close to the end of the tube; plunge the tube into a vessel of water; quit the string: the plate remains supported by the upward pressure of the water; raise the tube until the lead falls off; at this point the depth of the lead below the surface of the fluid will be about eleven times its thickness, for lead is about eleven times the weight of an equal bulk of water.

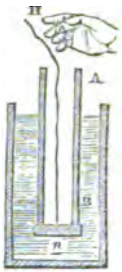


Fig. 16.

Exp. 3. Dip the end B of a small tube (Fig. 17) into quicksilver; stop the upper end A with the finger and lift up the tube from the quicksilver: a small column of quicksilver remains in the lower end of the tube. Plunge the end of the tube into a vessel of water to a depth rather more than 13½ times the length of the little column of quicksilver, then take away the finger: the quicksilver remains supported by the upward pressure of the water. It will be observed that quicksilver is about 13½ times the weight of an equal bulk of water.

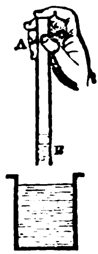


Fig. 17.

16. The upward pressure of a long column of water is strikingly exhibited in the *hydrostatic bellows.* Two boards, A and B, Fig. 18, are connected together by means of leather, as in the common bellows; a small pipe *a b c* communicates with the inside of the bellows; a heavy weight W is placed upon the upper board to show the effect of the pressure. Water is poured in at the mouth *c*, so as to fill the bellows as well as the tube.

Now, when water is poured into the tube, the upper board A, with its weight W, is lifted up by the pressure of the water beneath it. The bore of the pipe may be as small as you please, for the power of the instrument merely depends upon the height of the column of water *b c* in the small tube and the area of the board A B; that is to say, the weight W which is raised is equal to the weight of a column of water A *b c* standing on the upper board as a base and having *b c* as its perpendicular height. If the area of the board A *b* is one square foot, and the height of the column of water *b c* in the small tube is three feet, then the upward pressure upon the board will be equal to the weight of three cubic feet of water, or equal to 3000 oz. Now, by making the bore of the pipe very small we may suppose this effect to be produced by one ounce of water poured into the pipe; this ounce of water, therefore, is sufficient to counterbalance three thousand ounces placed upon the bellows board. The astonishing effect of a small column of water acting in this manner has been called the *hydrostatic paradox*.

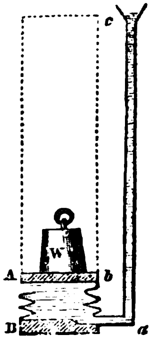


Fig. 18.

17. In this manner a strong cask (Fig. 19) filled with liquid may be burst by a few ounces of water poured into a long tube A communicating with the inside of the cask.

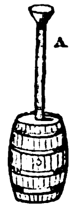


Fig. 19.

If a strong, square glass bottle, empty and firmly corked, be sunk in water, its sides will be crushed inwards by the pressure before it reaches a depth of ten fathoms.

If a corked empty bottle be let down into the sea, the cork is usually forced inwards at a certain depth.

When a ship founders at sea, the great pressure at the bottom forces water into the pores of the wood, and makes it so heavy that no part can ever rise again.

18. This law of pressure is also sometimes seen acting on a great scale in nature in the rending of rocks and mountains. Let A B (Fig 20) represent a long vertical fissure or crevice, communicating with an internal cavity C formed in the mountain, but without any outlet; now, when the fissure and cavity become filled with water, an enormous upheaving force is produced, sufficient, it may be, to cause a disruption of the mass D.

Fig. 20.

Acting in this way, water seems to be one of those great agents in nature which are constantly producing changes on the surface of

the globe. The freezing of water, under the same circumstances, also tends to produce similar effects.

Pressure on the Sides of Vessels.

19. It has been shown in Art. 12 that the pressure of water on a point in the side of a vessel increases with the depth of that point below the surface. Let A I (Fig. 21) be the section of the side of a rectangular vessel filled with water, and let the whole depth A I be 8 feet; then at the middle point E the depth A E will be 4 feet. Now, the pressure at I is produced by a column of water whose height is 8 feet, whereas the pressure at the middle point is produced by a column whose depth is 4 feet, which is just the mean or average between the top and bottom pressures, and in fact the average of all the pressures acting upon the side; hence the whole pressure upon the side will be produced by a column of water whose base is the area of that side with an average depth equal to half the whole height or depth of that side. We therefore have the following rule for finding the pressure on the side of a vessel: —

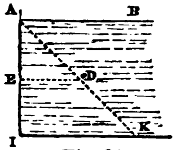


Fig. 21.

Multiply the area of the side, in feet, by one half its depth, and this product again by the weight of a cubic foot of water.

Conceive a surface equal to the side of the vessel to be laid in the bottom, then the pressure on this surface will be double the actual pressure on the side; for in this case the column of pressure is the whole depth, whereas the column of pressure on the side is only equivalent to half the whole depth.

It is important to observe that the pressure on the side of a vessel has nothing to do with the length of the vessel in the direction A B, for the pressure is simply equal to the product of the area of the side, the depth of its middle point, and the weight of a cubic foot of water: thus, —

Pressure on the side of a vessel = area side × half depth × wt. c. ft. water.

20. In consequence of the increase of pressure with the depth, *embankments* and *dams* are made broader at the bottom than at the top, (Fig. 22.) And, on the same principle, in order to have a cask equally strong, there should be more hoops placed towards the bottom than towards the top.

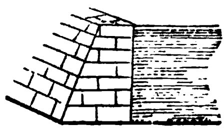


Fig. 22.

Centre of Pressure.

21. The centre of pressure is that particular point in the side of a vessel where the whole pressure upon it may be conceived to be applied without altering the effect.

Thus (Fig. 23) let the surface A Q D G be subject to the pressure of water; then there must be a point C in that surface where a single opposing pressure may be applied which shall exactly balance the whole pressure of the water; this point C is called the *centre of pressure*. This point must obviously lie in the vertical line E F, dividing the surface equally; moreover it must be nearer to the bottom than it is to the top; in fact its distance from the bottom is found to be one third the whole depth; that is to say, F C is equal to one third E F. An example will render the subject more plain: —

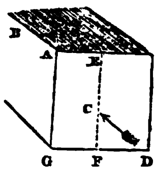


Fig. 23.

Ex. Let the breadth A Q = 4 feet, the depth A G or E F = 9 feet: required the position of the centre of pressure, and also the whole pressure of the water.

Here the distance of the centre of pressure from the bottom of the vessel is equal to $\frac{1}{3}$ of 9 feet, or 3 feet.

To find the pressure, we have

Area surface A Q D G $= 4 \times 9 = 36$ sq. feet;

Pressure on A Q D G $=$ area $\times$ $\frac{1}{2}$ depth $\times$ wt. c. ft. water.

$= 36 \times \frac{1}{2}$ of 9×1000.

$=$ 162,000 oz., or 10,125 lbs.

Here a pressure of 10,125 lbs. applied at C would counterbalance the pressure of the water upon the whole surface.

It may be worthy of observation, that a single hoop, placed upon a barrel at one third the whole height from the bottom, would counterbalance the pressure of the liquid upon the staves.

Specific Gravity.

22. Bodies differ very much in their density, or in the quantity of matter which they contain in a given bulk; thus the weight of a lump of lead is more than forty times the weight of an equal bulk of cork, and the weight of a piece of platinum is nearly double the weight of an equal bulk of lead. The *specific gravity* of a body is its weight as compared with the weight of an equal bulk of some other body, taken as a standard. For the sake of convenience, pure water, at the temperature of 60°, is taken as the standard by which the specific gravities of all other substances are compared. Taking the specific gravity of water as

unity, the specific gravity of any other substance is expressed by the number of times that it is heavier than an equal bulk of water: thus iron is 8 times the weight of an equal bulk of water; therefore the specific gravity of iron is 8; and so on to other cases. Now, the weight of a cubic foot of water is exactly 1000 ounces; hence we find the weight of a cubic foot of any substance by simply taking its specific gravity as so many thousands of ounces; thus the weight of a cubic foot of iron is 8000 ounces.

23. A body sinks or floats, according as its specific gravity is greater or less than the fluid in which it is immersed; and when the specific gravity of the body is equal to that of the water, the body, upon being immersed, neither rises nor falls, but remains as it were suspended in the fluid at all depths.

24. The most important laws, regulating the pressure of fluids on solids immersed in them, are as follows:—

1. When a solid body floats on a fluid, the weight of the fluid displaced is equal to the weight of the body.

2. When a heavy body is weighed in water, the weight which the body loses is due to the upward pressure or buoyancy of the water, and is equal to the weight of the water displaced.

25. The following experiments are intended to illustrate these important laws, as well as other properties of fluids depending upon their specific gravity.

EXPERIMENTS.

Fig. 24.

Exp. 1. Fluids may be placed upon each other in the order of their specific gravities; thus mercury, water, oil, and spirits may be placed upon each other in a test tube, as in the annexed cut. (Fig. 24.)

Exp. 2. Fluids may be made to balance each other by their opposing pressures, and in such cases the columns of the fluids are reversely as their specific gravities. Take a bent tube, (Fig. 25,) introduce a little mercury into one leg, and some water into the other: the column of water will be about 13½ times the height of the mercury, in order that they should balance each other. From this it follows that mercury is about 13½ times the weight of water.

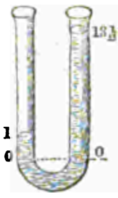


Fig. 25.

Exp. 3. Try water and muriatic ether, as in the last experiment: the column of ether will be about 1½ times the column of water.

Exp. 4. A light fluid will rise within a heavy one. Take a small bottle filled with red wine, (or any colored liquor specifically lighter than water;) invert it with its mouth at the bottom of the vessel of water: the wine rises through the water.

Exp. 5. A heavy fluid will sink in a lighter one. Take a small bottle filled with diluted sulphuric acid, colored red by the tincture of litmus; invert the mouth of the bottle at the top of some hot water: the heavy colored liquid descends through the water.

Exp. 6. Fill a vessel A (Fig. 26,) having an opening *a*, with water, until it begins to run out at *a*; place any floating body W on the surface of the water; the body sinks to a certain depth, and thereby displaces a portion of water equal to the bulk of that part of the body which is immersed; receive this water in the vessel B; weigh the water thus received, and it will be found to be equal to the weight of the floating body.

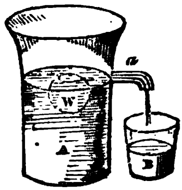


Fig. 26.

Exp. 7. Again: fill the vessel A with water until it begins to run out at *a*; immerse any body W completely in the water, then a quantity of water will run out, into the vessel B, equal in bulk to the body immersed; weigh this water, and it will give the weight of water equal in bulk to the body. The actual weight of the body divided by the weight of this water which it displaces will give the specific gravity of the body: thus if the weight of the body is 6 ounces, and the weight of the water which it displaces 3 ounces, then the weight of the body will be 2 times the weight of an equal bulk of water; that is, the specific gravity of the body will be 2, that of water being 1. This is a simple, though somewhat rude, method of finding the specific gravity of a body.

Exp. 8. Two equal weights A and B (Fig. 27) are duly balanced over a pulley; place one of them A at the bottom of an empty vessel; pour water into the vessel; the equilibrium is destroyed by the buoyancy or upward pressure of the water upon the weight A, and it consequently ascends to the surface of the fluid. Hence it requires less force to raise a body in water than it does to raise the same body in air.

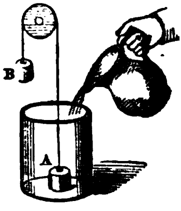


Fig. 27.

Exp. 9. Take a small long-necked bottle, and put some shot into it, so as to make it float to a convenient depth in water; make a mark on the neck of the bottle at the level of the water; now float the bottle in some other liquid, such as oil or beer, whose specific gravity is less than that of water; the bottle sinks to a greater depth.

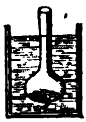


Fig. 28.

Here the bulk of the displaced liquid is greater according as its specific gravity is less.

Exp. 10. To show that *the weight which a body loses in water is equal to the weight of the fluid displaced:* place a hollow cylinder *a* on one scale of a balance, and suspend to this scale a solid metal cylinder *b*, which exactly fits the hollow formed in the other cylinder *a*; place a weight *c* on the opposite scale so as to restore the balance; plunge *b* into a vessel of water; the scale *c* descends: now fill the hollow cylinder *a* with water; the equilibrium is restored. It will be observed that the water which restored the equilibrium is equal to the bulk of the body *b*.

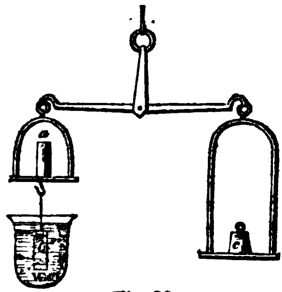


Fig. 29.

Exp. 11. Balance a glass of water in a pair of common scales; suspend a two ounce brass weight by a fine thread hold the weight, thus suspended, in the water; then the scale on which the glass of water is placed descends, and it will require about a quarter of an ounce to restore the equilibrium. This quarter of an ounce is the weight of water equal in bulk to the brass weight; therefore brass is about eight times the weight of an equal bulk of water.

To find the Specific Gravity of Liquids by Means of a small Bottle.

26. Take a small glass bottle having a long neck; find the weight of this bottle; fill it with pure water up to a certain mark made upon the neck; weigh the bottle and water; then the difference between these weights will give the weight of the enclosed water. Pour out the water and introduce the liquid, whose specific gravity is to be determined, to the height of the mark made upon the neck of the bottle; weigh the bottle and liquid; then the difference between this weight and that of the bottle itself will give the weight of the enclosed liquid. Now, having thus obtained the weight of equal bulks of water and the liquid, the latter weight divided by the former will give the specific gravity of the liquid. For example, let the weight of the empty bottle be 200 grains, that of the bottle filled with water 800 grains, and that of the bottle and liquid 1100 grains; then we have

$$\text{Weight of the water} = 800 - 200 = 600,$$
$$\text{Weight of the liquid} = 1100 - 200 = 900;$$
$$\text{Specific gravity of the liquid} = \frac{900}{600} = 1\tfrac{1}{2}.$$

To find the Specific Gravity of Bodies by the Hydrostatic Balance.

27. The *hydrostatic balance* differs from an ordinary one only in having a hook attached to the under side of one of the scales. The body, whose specific gravity is to be found, is suspended from the hook by a horse hair, and then its weight is determined. It is now weighed in water, and thus its loss of weight is ascertained. Now, it has been explained (see Exp. 10) that the weight which a body loses in water is equal to the weight of a portion of water equal in bulk to the body, and hence we have the following rule: —

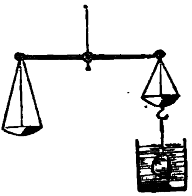


Fig. 30.

The specific gravity of a body is equal to its weight divided by the weight which it loses in water.

Ex. The weight of a solid body is 200 grains, but its weight in water is only 150 grains: required the specific gravity of the body.

Here the loss of weight in water, or, what is the same thing, the weight of water equal in bulk to the body $= 200 - 150 = 50$; but the weight of the body itself $= 200$;

The specific gravity of the body, or the number of times which it is heavier than an equal bulk of water, $= \dfrac{200}{50} = 4$.

28. The specific gravity of *liquids* may be found by the hydrostatic balance, in the following manner: —

Weigh a solid body in water, as well as in the liquid whose specific gravity is to be determined; then the loss in each case will be the respective weights of equal bulks of water and the liquid; therefore —

The loss of weight in the liquid, divided by the loss of weight in the water, will give the specific gravity of the liquid.

The solid body used in this process is usually a heavy piece of glass, suspended from the scale by means of a fine platinum wire.

Ex. A heavy piece of glass loses 2 ounces when weighed in water, and 3 ounces when weighed in diluted sulphuric acid: required the specific gravity of the acid.

Here the weights of equal bulks of the two liquids are 2 and 3 ounces respectively.

Specific gravity of the acid $= \frac{\text{wt. acid}}{\text{wt. water}} = \frac{3}{2} = 1\frac{1}{2}$.

29. A false gold coin may be detected by finding its specific gravity, for as pure gold has a greater specific gravity than any of the metals, such as silver or copper, with which it may be adulterated, the counterfeit coin will have a less specific gravity than standard gold. Tradesmen use a very simple method for detecting a false coin. A standard coin must have a proper weight, and also a certain bulk corresponding to its weight; now a false coin, having the proper weight, will have a greater bulk than a true one; hence the tradesman employs two tests for ascertaining a good coin; he first weighs it, and if this is found correct, he then tries to pass it through a slit made exactly to fit the thickness and diameter of a standard coin; if the coin under examination does not pass through this slit, he concludes that the coin is counterfeit.

Specific Gravity of Bodies determined by the Hydrometer.

30. These instruments depend upon the principle, that the weight of a floating body is equal to the weight of the fluid which it displaces.

Nicholson's Hydrometer is so contrived as to determine the specific gravity of solids as well as liquids. In Fig. 31, B is a hollow ball, to which is attached a fine wire *s*, supporting a dish C for receiving weights; proceeding from the under side of the ball is the stirrup D, carrying a heavy dish F for preserving the stability of the instrument when it floats, and for holding any solid body whose specific gravity is to be determined. The instrument is floated in pure water, and a weight of 1000 grains is put into the dish C; now, the weight of the instrument is so adjusted that it sinks to about the middle of the fine stem; and a mark *s* is made at this point.

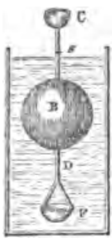


Fig. 31.

31. To determine the specific gravity of a *liquid:* —

Place the instrument in the liquid, and put weights into the dish C until the mark *s* on the stem sinks to the level of the surface of the liquid. These weights added to the weight of the instrument will be equal to the weight of the liquid displaced; but the weight of the instrument added to 1000 oz. is equal to the weight of an equal bulk of water; therefore the former sum divided by the latter will give the specific gravity of the liquid. For example, let the weight of the instrument be 3000 grains, the weight put on the dish C equal to 200 grains, then we have

$$\text{Weight of displaced water} = 3000 + 1000 = 4000;$$
$$\text{" " " liquid} = 3000 + 200 = 3200;$$
$$\text{Specific gravity of liquid} = \frac{3200}{4000} = .8.$$

32. To determine the specific gravity of a *solid* : —

Place the instrument in water, and put the solid in the upper dish C; add weights to this dish until the mark *s* on the stem sinks to a level with the fluid; then these weights, together with the weight of the body, must be equal to 1000 grains; therefore the weight of the body itself must be equal to 1000 grains less by these weights. For example, if 600 grains are added to the dish C, then the weight of the body is equal to 1000 grains less by 600 grains, or 400 grains.

Let the body be now placed in the lower dish F, and, as before, let weights be placed in the upper dish until the mark *s* sinks to a level with the water; then these weights, together with the weight or downward tendency of the body *in the water* are equal to 1000 grains; therefore the weight of the body in water is equal to 1000 grains less by the weights added to the upper dish. Suppose these weights to make up 800 grains; then the weight of the body in water is equal to 1000 grains less by 800 grains, or 200 grains.

Now, having obtained the weight of the body, 400 grains, and also its weight in water, 200 grains, the loss of weight in water will be equal to the difference of these weights — that is, in this case, the loss of weight in water will be equal to 400 grains less by 200 grains, or 200 grains; hence we have, by Art. 27, —

$$\text{Specific gravity of the body} = \frac{\text{wt. body.}}{\text{wt. lost in water}} = \frac{400}{200} = 2.$$

Let us take another example. In finding the weight of the body, suppose that 300 grains were put into the dish; and in finding the weight of the body in water, suppose that 400 grains were put into the dish; then we have, —

$$\text{Weight of the body} = 1000 - 300 = 700;$$
$$\text{Weight of body in water} = 1000 - 400 = 600;$$
$$\text{Weight lost in water} = 700 - 600 = 100;$$
$$\text{Specific gravity of the body} = \frac{700}{100} = 7.$$

33. *Sike's Hydrometer*, which is the one employed by excisemen, has a graduated stem, and the instrument is always used in connection with a book of tables. The depth to which the stem sinks is observed, and at the same time the thermometer and barometer are also noted; these numbers being sought out in the tables, the corresponding specific gravity is found in its proper column.

The hydrometer is chiefly used for ascertaining the adulteration of

spirits. The strongest spirits, or those which contain the largest quantity of alcohol, have the least specific gravity, and consequently the hydrometer sinks in them to the greatest depth. The specific gravity of pure alcohol is nearly $\frac{8}{10}$ or .8, and that of *proof spirits*, which is a mixture of equal parts of alcohol and water, is about $\frac{9}{10}$ or .9. Spirits are said to be *above proof* or *under proof*, according as they contain a larger or smaller proportion of alcohol.

Floating Bodies.

34. It has already been explained that, when a body floats in a fluid, the weight of the fluid displaced is always equal to the weight of the body. Let A B C D (Fig. 32) be a piece of wood floating in water; then the weight of the water displaced, viz., E F C D, is equal to the whole weight of the wood. The upward pressure on the bottom D C is the same as that which would support a portion of fluid equal in bulk to the displaced fluid E F C D; and as the downward pressure of the body is equal to the upward pressure of the fluid, it follows that the weight of the body is equal to the weight of the fluid displaced.

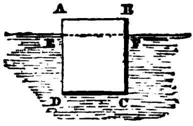


Fig. 32.

Hence it is that iron vessels float in water; for as they are made hollow, it is easy to see that the displaced water must be much heavier than the whole weight of the metal.

35. In order that a body may float with stability, it is requisite that its centre of gravity should lie as low as possible. For this reason ballast is laid in the bottoms of ships; and, in like manner, when a boat is in danger of being overturned by the violence of the winds or the rolling of the waves, it tends to lessen the danger when the passengers lay themselves flat at the bottom of the boat. A body is most stable when it floats upon its greatest surface; thus a plank floats with the greatest stability when it is placed flat upon the water, and its position is unstable when it is made to float edgewise. A body will only remain at rest in a fluid when the centres of gravity of the whole body and that of the displaced fluid are in the same vertical line; for if the body is shifted from this position, the upward pressure of the water, as well as the downward pressure of the body, tends to bring it to its original position. In Fig. 33, No. 1, C represents the centre of gravity of the body, and B that of the fluid displaced, where C and B are in the same vertical line. Now, when the body is shifted from this posi-

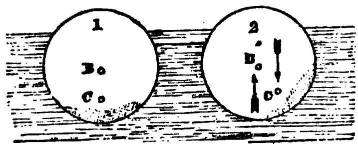


Fig. 33.

tion, as in No. 2, the gravity of the body, as well as the buoyancy of the fluid, tends to bring the body to its first position.

Additional Facts.

A stone which on land requires the strength of two men to lift it may be lifted in water by one man. A boy will often wonder why he can lift a certain stone to the surface of the water, but no further.

When a person lies in a bath, the limbs are so nearly supported by the water as to require scarcely any exertion on the part of the individual.

The human body, with the chest full of air, naturally floats with a bulk of about half the head above the water. That a person in water, therefore, may live and breathe, it is only necessary to keep the face uppermost.

The common contrivances called *life preservers*, for preventing drowning, are strings of corks put round the chest or neck, or air-tight bags, inflated, and applied round the upper part of the body.

Fishes can change their specific gravity by diminishing or increasing the size of a little air bag contained in their bodies.

A ship draws less water, or sails lighter, by one thirty-fifth, in the heavy salt water of the sea than in the fresh water of a river; and, for the same reason, swimming in sea water is easier than in a pond or river.

Many kinds of wood that float in water will sink in oil.

A man floats on mercury as the lightest cork floats on water.

Cream rises in milk, and forms a covering to it.

The equilibrium of floating bodies is a subject of great practical importance, but it would require a knowledge of mathematics to enter upon it more fully.

Capillary Attraction.

36. When the extremity of a glass tube having a very small bore is plunged into water, the fluid is found to rise in the tube. This exception to the law of level of the surface of a fluid is said to take place in consequence of the attraction of the interior surface of the tube upon the water; and it is called *capillary* attraction, for it takes place in *capillary* tubes, or tubes having a *hair-like* bore. The adhesion of the water to the sides of the tube is shown by the concave form of the surface of the water in the tube; hence it is always essential to the

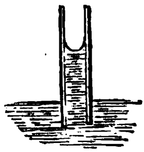


Fig. 34.

effect that the tube should be susceptible of being *wetted*, for when the tube is soiled with any oily substances the water becomes depressed in consequence of the repulsion which the oil has for water. If the capillary tube be immersed in mercury, then the mercury becomes depressed in the tube, in consequence of the repulsion which the surface of the glass has for the mercury.

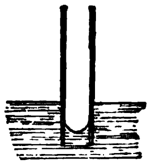


Fig. 35.

37. The height to which water rises in these tubes is in proportion to the smallness of their diameters; thus in two tubes, one of which is double the diameter of the other, the fluid will rise to double the height in the small tube that it will do in the other. This law is beautifully illustrated by the following experiment (Fig. 36): Take two plates of glass, kept in contact at one extremity and a little apart at the other; immerse them in water, as shown in the figure: the water rises between the plates, forming a curved line called the hyperbola. It will be observed that the height of the water at any part is greater according as the distance between the plates at that part is less.

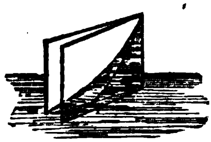


Fig. 36.

38. If two balls of wood, (Fig. 37,) each of which is capable of becoming *wetted*, be placed upon water, their sides will draw up the water; and if they are brought near one another, so that the elevations of the fluid may interfere, the balls will approach one another — that is, they will appear to attract one another. In the same way little floating bodies are attracted to the sides of the wood. If one of the balls be soiled with oil, (Fig. 38,) the fluid about that ball will be depressed; and if they are brought near one another, as in the last case, they will repel one another. These facts depend upon the principle of capillary attraction and repulsion. On the same principle a great many phenomena in nature may be explained. For example, the melted tallow of a candle rises in the wick; and water rises through the fine pores of sugar.

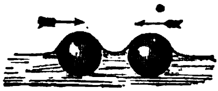


Fig. 37.

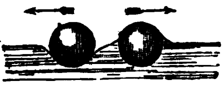


Fig. 38.

39. Take an ordinary sized glass tube, and tie a piece of thin bladder, or any fine membranous substance, over one end; into this tube pour some thick sirup of sugar and water; immerse the tube in water; then in the course of a few hours the fluid in the tube will have risen to the

height of several inches above the level of the water in the vessel. Here it appears that the thinner fluid, the water, passes more rapidly through the pores of the bladder into the tube than the thicker fluid, the sirup, passes out of it. This remarkable phenomenon is called *Endosmose* and *Exosmose*, the former term meaning *to tend inwards*, the latter *to tend outwards*. In the foregoing experiment the water passes through the pores of the bladder into the tube by endosmose, and the thicker fluid passes out of the tube by exosmose. On this principle a great many important phenomena of nature may be explained.

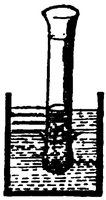


Fig. 39.

HYDRAULICS.

40. Having explained the leading phenomena resulting from the pressure and weight of fluids in a state of rest, we now come to treat of the motion of fluids.

Velocity with which Water spouts out of a Vessel.

41. When a hole is made in a vessel filled with water, the fluid spouts out in a jet with greater or less velocity according to the depth of the hole below the surface of water. The following simple law obtains in reference to the efflux of the water, supposing that it underwent no resistance from friction or other causes. The velocity of a jet B or C (Fig. 40) proceeding vertically from a vessel is such as to cause the water to rise up to the level of the water in the vessel, as shown in the annexed cut. This seems to arise from the principle that water always seeks its level, for the jet tends to rise to the level A D of the water in the vessel. Now, if the velocity with which the fluid issues from the aperture B be such as to carry the fluid through the perpendicular height B A in opposition to gravity, it follows that this velocity is equal to that which a body would acquire in falling freely through this space. Hence we conclude that *a fluid issues from an aperture with a velocity equal to that which a body would acquire in falling through a space equal to the depth of the aperture below the surface of the fluid:* thus, if A B is 16 feet, the velocity of the jet will be 32 feet per second; for this is the velocity which a body acquires in falling through the space of 16 feet.

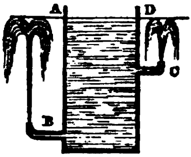


Fig. 40.

42. In Fig. 41 the aperture is made in the bottom of the vessel; and the theoretical velocity with which the water issues is, as in the preceding case, equal to the velocity which the fluid would acquire in falling freely down from *m n* to *b c*.

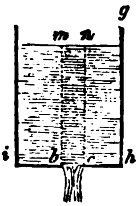


Fig. 41.

Now, it is shown in mechanics that the velocity acquired by a falling body is as the square root of the space through which it falls; therefore *the velocity with which water spouts out at any aperture in a vessel is as the square root of the depth of the aperture below the surface of the water.* It must, however, be observed that there are different obstructions which tend to modify this rule in practice. When water is conveyed from a cistern to any considerable distance in pipes, as shown in the annexed cut, (Fig. 42,) the friction of the water, as it moves in the pipe, together with the obstructions presented by the bendings, &c., tends very much to retard the motion of the fluid. By the theoretical rule above given, the velocity of discharge would be due to the vertical depth A B through which the water falls; but, owing to the resistances just mentioned, this is very far from being practically true; in such cases the engineer must have recourse to some formula derived from experiment.

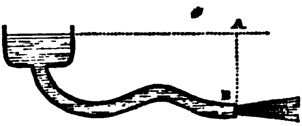


Fig. 42.

It is a curious fact that more water issues from a vessel through a short pipe than through a simple aperture of the same diameter as the pipe; and still more, if the pipe be funnel-shaped, or wider towards its inner extremity. The explanation is, that the issuing particles, coming from all sides to escape, cross and impede each other in rushing through a simple opening, whereas the tube, leading the water by a more gradual inclination towards the point of exit, considerably prevents the crossing among the particles.

To regulate the Supply of Water.

43. When water is conveyed by pipes to cisterns, it is necessary that no more water should flow into the cistern than is required. This adjustment is effected by a simple and ingenious contrivance called the *float cock*. Fig. 43, P represents a pipe conveying water to the cistern A; B is a hollow ball of metal, called the float, which is connected with a cock C, opening and closing the pipe in such a manner that when the float is raised the cock

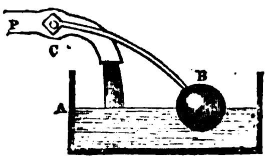


Fig. 43.

stops the passage of the water, and, on the contrary, when the float is depressed, the cock allows the water to flow through it. Now, when there is a deficiency of water in the cistern, the cock C is open and a fresh supply is allowed to run in; but as the water rises, the float B by its buoyancy also rises, and at length turns the cock so as to stop the supply of water; again, when water is taken out of the cistern, the float falls with the water, and at length opens the cock, which admits a fresh supply of water; and so on.

Springs and Artesian Wells.

44. Springs are formed by the rain and moisture which fall upon hills and mountains. The upper crust of mountains is usually composed of loose, porous layers of substances which allow water to pass through them, and also of layers of clay and solid substances which are impervious to water. Let the accompanying cut (Fig. 44) represent the section of a mountain or hill, where A is composed of loose or porous substances, *c* a layer of clay or some substance which stops the descent of the water; then the water which filters through A will run along the top of *c* until it is discharged at F in the form of a natural spring or fountain; B is composed of loose or porous substances; D some substance which stops the descent of the water; *w* is an artesian well, or vertical hole, which has been bored by workmen, and metal pipes put down it; now, the rain water, together with the water which arises from melting snow and ice, sinks through B and flows along the surface of D until it finds a vent up the pipes forming the artesian well *w*. Let us further suppose that *b* is a rent or fissure in which water is collected; then the height to which the water will rise in the well *w* will be on the same level with the water in the fountain *b*.

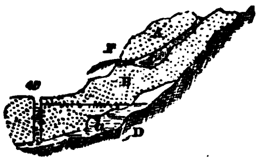


Fig. 44.

Canals and Locks.

45. Canals are artificial streams of water, upon which barges are floated for the purpose of conveying heavy goods from one place to another. The water in canals is usually obtained from springs or from some neighboring river. In order that the barges may sail with equal ease in both directions of the canal, it is requisite that the surface of the water should be level; to accomplish this, the canal is sometimes carried over valleys by means of bridges and embankments, and sometimes it is even made to pass through hills by means of tunnels; but the most

common contrivance for maintaining the level of surface is that of locks or floodgates. Fig. 45 represents a section of a lock, made at a place where there is a sudden fall of the ground along which the canal has to pass: A B and C D are the two gates which completely intercept the course of the water, but at the same time admit of being opened and closed; A H is the level of the water in that part of the canal lying above the gate A B, and F G the level lying below the gate C D; now, when a barge is about to pass from A H to F G, a side sluice, not shown in the figure, is first opened, which allows the water to flow from A H into the space A E F C between the gates until it attains the common level H A C; the gate A B is then opened, and the barge floats into the space between the gates; the gate A B is now closed, and a side sluice is opened, which allows the water to flow from the space A E F C until it comes to the common level E F G; the gate C D is then opened, and the barge floats out of the locks along the canal. It is easy to see, by reversing the steps of this process, that the barge may be floated in the contrary direction. A horse, moving along the side of the canal, is usually employed to pull the barge through the water.

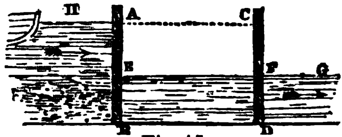


Fig. 45.

HYDRAULIC MACHINES.

Water Wheels, &c.

46. Fig. 46 represents an *undershot wheel*, turning on the axle A; M N is a current of water, which, striking against the *float boards*, causes the wheel to revolve on its axle A; on this axle is fixed the toothed wheel which drives the machinery.

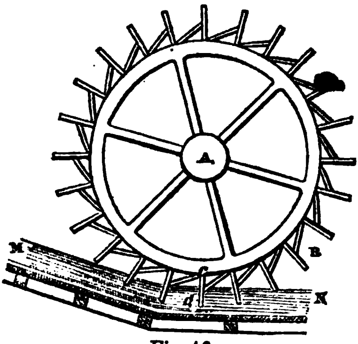


Fig. 46.

In Poncelet's undershot wheel the float boards are curved towards the direction of the current, so that the water rolls up their surface,

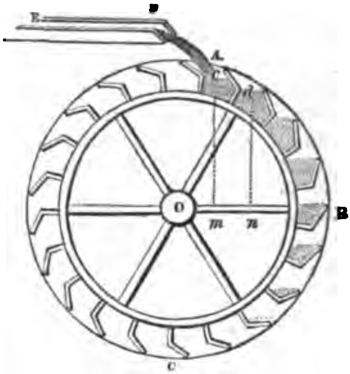


Fig. 47.

and does not leave them until all its work is spent upon the wheel.

Fig. 47 represents an *overshot wheel*, turning on its centre O; E F is a stream of water flowing over the top of the wheel into the buckets *c d*, &c., fixed upon the rim of the wheel; the gravity of the water in these buckets causes the right hand side A B C of the wheel to be heavier than the other side, where the buckets are empty, being all turned upside down; hence the wheel revolves in the direction A B C. Let *c m* and *d n* be perpendiculars let fall from the centres of gravity of the water in the two buckets *c* and *d* respectively; then O *m* will be the leverage of the water in the bucket *c*, and O *n* that of the bucket *d*; the bucket B, in the horizontal line O B, will have the greatest leverage, and consequently will act with the greatest efficiency in moving the wheel. As the buckets descend below B, they not only act with a decreasing leverage, but the water which they contain is continually flowing out of them until they arrive at C, when they become completely empty.

Barker's Mill.

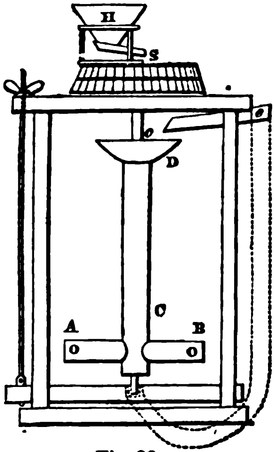


Fig. 28.

47. This simple and elegant engine is moved by the efflux of water undergoing pressure. C D is a hollow cylinder turning on a vertical axis; A B is a horizontal cylinder communicating internally with the former; at the extremities of this horizontal cylinder two apertures A and B are made in the sides, opening in *opposite* directions. On the continuation of the vertical axis, the upper millstone S is fixed, and therefore revolves with it; H is the hopper delivering the corn to be ground. A continuous stream of water flows through the pipe *e c* into the cylinder C D. Let us suppose that the cylinder

C D, with its horizontal branch A B, to be filled with water; then the pressure of this column of fluid will cause the water to be projected in jets from the orifices A and B in opposite directions; then the recoil or reaction of these jets upon the extremities of A and B gives a rotatory motion to the whole machine upon the vertical axis.

Or, to take another view of the principle of action in this machine: if the orifices at A and B were closed, the column of fluid in the vertical tube C D would press equally on both sides of the horizontal tube A B; but when the orifices A and B are opened, the pressure on these parts is released, while the pressure upon the sides opposite to them remains the same; hence the tube A B revolves in the direction of the greater pressure — that is, in a direction contrary to that of the jets of water.

The Archimedean Screw.

48. This simple and beautiful contrivance for raising water was invented by the great Archimedes. It simply consists of a pipe wound, in a spiral form, about a solid cylinder A B, which is made to revolve on its axis by means of the winch H. The lower orifice *a* of the spiral tube dips into the water to be raised, and it is discharged at the upper orifice. As the cylinder is turned round, the water, which enters the orifice *a* at each revolution, runs down a series of inclined planes, until it flows out at the upper orifice. In order to illustrate this action, let a marble be put into the pipe at *a*, then as the cylinder is turned round, the marble will continue to roll down a succession of inclined planes (formed at each revolution of the cylinder) until it is discharged at the upper orifice.

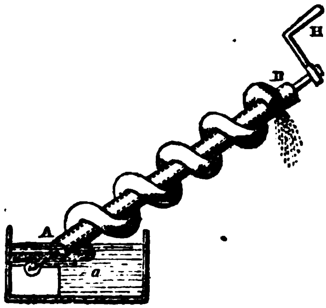


Fig. 49.

Exercises on Hydrostatics and Hydraulics.

1. In Fig. 9, Art. 11, suppose the large piston P to contain 40 square inches, and the small one, *p*, 2 square inches; what upward pressure will be produced upon the large piston by a downward pressure of 14 lbs. exerted upon the small one?

Pressure on 2 in. of the piston $= 14$ lbs.;

" 1 in. " $= \frac{14}{2} = 7$ lbs.;

" 40 in. " $= 40 \times 7 = 280$ lbs.

2. Required the same as in the last example, when the surface of the large piston is 25 inches, that of the small one 3 inches, and the pressure applied to it 30 lbs. *Ans.* 250 lbs.

3. In Fig. 11, Art. 13, let the area of the base D C contain 4 square feet, and let the depth of the water G C be 5 feet: required the pressure on the bottom of the vessel. *Ans.* 20,000 oz., or 1250 lbs.

4. In the hydrostatic bellows, (see Fig. 18, Art. 16,) the upper board A contains 2 square feet of surface, and the height of the water in the tube *b c* is 4 feet: required the weight W which will be supported on the bellows. *Ans.* 8000 oz., or 500 lbs.

5. In a flood gate (see Fig. 23, Art. 21) A Q D G, let the breadth A Q = 5 feet, the depth A G or E F = 6 feet: required the position of the centre of pressure, and also the pressure of the water upon the gate.

Ans. The centre of pressure is two feet from the bottom; and the whole pressure is 5625 lbs.

6. In finding the specific gravity of a liquid, (see Art. 26,) suppose the weight of the empty bottle to be 300 grains, the weight of the bottle filled with water to be 900 grains, and the weight of the bottle filled with the liquid to be 700 grains: required the specific gravity of the liquid. *Ans.* $\frac{2}{3}$, or 666 +.

7. The weight of a solid body is 300 grains, but its weight in water is 250 grains: required the specific gravity of the body. (See Art. 27.) *Ans.* 6.

8. A solid body lost 40 grains when weighed in water, and 70 grains when weighed in oil of vitriol: required the specific gravity of the vitriol. (See Art. 28.) *Ans.* $1\frac{3}{4}$.

9. In finding the specific gravity of a liquid by Nicholson's Hydrometer, (see Art. 30,) let the weight of the instrument be 3000 grains, and let the weight put in the dish C (to sink the instrument to the mark *s* when floated in the liquid) be 1400 grains: required the specific gravity of the liquid. *Ans.* 1.1.

10. A cubical piece of wood, whose side is 2 feet, sinks to the depth of $1\frac{1}{2}$ feet when floated on water: required the specific gravity of the wood. (See Art. 34.)

Here the wood contains 8 cubic feet; and the volume of the water displaced $= 2 \times 2 \times 1\frac{1}{2} = 6$ cubic feet. Now, the weight of this displaced water is 6000 oz., but this is also the weight of the floating body;

Weight of 8 c. ft. of the wood $= 6000$ oz.;

" 1 c. ft. " $= \frac{6000}{8} = 750$ oz.;

But the weight of 1 c. ft. of water is 1000 oz.;

Specific gravity of the wood $= \frac{750}{1000} = .75$.

This result might at once be obtained by dividing the depth of immersion by the whole depth of the body: thus, $\frac{18}{24} = \frac{3}{4}$, or .75.

11. Required the same as in the last example, when the side of the cube is 1 foot, and the depth of immersion 8 inches. *Ans.* $\frac{2}{3}$.

12. With what velocity will water issue from an orifice made at the depth of 4 feet below the level of the fluid? (See Art. 42.)

Ans. 16 ft. per second.

Here it will be observed that a body will fall through 4 ft. in $\frac{1}{2}$ of a second.

13. Required the same as in the last example, when the orifice is 64 feet below the level of the fluid. *Ans.* 64 feet per second.

PNEUMATICS.

1. PNEUMATICS is that part of Natural Philosophy which treats of the motion and pressure of aeriform or elastic fluids, such as the air which forms the atmosphere.

2. The atmosphere every where surrounds the globe, and extends to the height of about fifty miles above the tops of our highest mountains. Although the air is invisible, and seems as nothing to the vulgar eye, yet it is a material substance, possessing all the essential properties of matter in common with solid and liquid bodies.

3. Air retards the motion of bodies.

Thus, when a flat board is rapidly moved through the air, a considerable resisting force is felt; and it is well known that the velocity of railway trains is much affected by the resistance of the air. Winds, air in motion, drive our ships through the ocean, and perform useful labor in our wind mills. The air, driven on with terrific violence by the hurricane or the tornado, sweeps over the earth and carries desolation and ruin to the abodes of man. The air, in the storm and tempest, lifts up the mountain billows of the deep, and dashes in pieces the stately bark as she bears to our shores the wealth of other lands. It is plain that the agent which is capable of producing such effects must be *material.*

4. The air, like all material bodies, is *impenetrable;* that is to say, the space occupied by air cannot contain any other body at the same time.

EXPERIMENTS.

Exp. 1. Invert a tall glass A over water, as in the accompanying cut; the water does not rise completely within the glass on account of the air which is in it. To render the experiment more apparent, a small cork is placed upon the water.

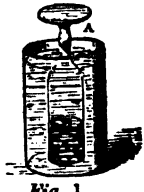


Fig. 1.

This experiment also shows the elasticity of the air; for as the glass is pressed down, the air that is in it occupies less and less space, and the force requisite to

keep the glass down, or to balance the elastic force of the air, increases with the decrease of the bulk of the air in the glass.

Exp. 2. Fill a large bottle with water; blow air into the bottle by means of a bent tube, as shown in the figure; in this case, the air *displaces* the water.

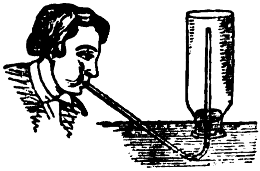


Fig. 2.

In like manner, air may be transferred from one vessel to another. Here *b* (Fig. 3) represents a vessel filled with water, and having its open mouth inverted in the same fluid; *e* is another vessel containing air; the lower edge of *e* is brought to the mouth of *b*, and as the upper end of *e* is depressed, the air rises in bubbles into the vessel *b*, and displaces the water; thus all the air in the vessel *e* may be transferred, without any loss, into the vessel *b*.

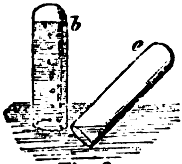


Fig. 3.

It will be hereafter explained, that the water is sustained in *b* by the pressure of the atmosphere.

Exp. 3. Take a bent tube of glass, open at both extremities; place the fore finger on the extremity B, and pour water into A; the fluid does not fill the branch B on account of the air which it contains. Take away the finger: then the air is displaced from B, and the water stands at the same level in both branches of the tube.

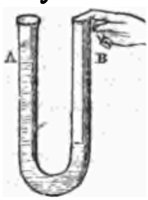


Fig. 4.

5. Air has *weight.*

Exp. Take a Florence flask F, having a stop cock S attached to it; exhaust the air from it by means of an exhausting syringe, (see Art. 18;) weigh the bottle thus exhausted of air; open the cock, and allow the external air to fill the bottle; the scale on which the bottle is placed will preponderate, and it will require about one pennyweight weight to restore the balance. This is the weight of the air in the bottle.

Fig. 5.

Having found the weight of any known bulk of air, the weight of any other bulk of it may be easily determined. For example, suppose that the bottle contains 60 cubic inches of air, and that its weight is 18 grains: let it be required to find the weight of 100 cubic inches.

$$\text{Weight } 60 \text{ c. in. of air} = 18 \text{ grains};$$

$$\text{"} \quad 1 \text{ c. in. of air} = \frac{18}{60} \text{ grains};$$

$$\text{"} \quad 100 \text{ c. in. of air} = \frac{18 \times 100}{60} = 30 \text{ grains}.$$

The weight of 100 cubic inches of atmospheric air, at a mean temperature, has been found to be 31.01 grains. From this it follows that *a cubic foot of air weighs more than an ounce*, and that water is about eight hundred times the weight of an equal bulk of air.

6. Light bodies float in the air in the same way as a piece of cork floats in water: thus soap bubbles, balloons, clouds, and smoke float in the air. Now, when a body floats in a fluid, it is lighter than that fluid; the air, therefore, is heavier, bulk for bulk, than balloons or any of those bodies which float in it.

PRESSURE OF THE AIR.

7. The air, like all other material substances, gravitates towards the earth; from this it necessarily follows that the atmosphere must exert a pressure upon all terrestrial bodies, and moreover that the pressure on any given surface must be equal to the weight of the column of air above that surface. Air, being a fluid, presses equally in all directions. (See HYDROSTATICS, Art. 9.)

The fact of atmospheric pressure is clearly established by the following easy experiments: —

EXPERIMENTS.

Exp. 1. Take a glass tube, open at both ends, and fit a plug or piston P to it, by wrapping some cotton round the end of a wire; insert the lower extremity of the tube in water, as shown in the figure; raise the piston: the water rises in the tube by the pressure of the atmosphere upon the surface H R of the water in the vessel.

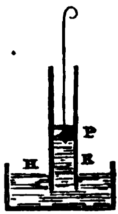


Fig. 6.

This experiment explains the principle of the common syringe. Push the piston P (Fig. 7) to the bottom of the barrel; insert the nozzle O into some water, and then raise the piston: the water rises into the syringe by the pressure of the atmosphere. When the piston is forced downwards, the water escapes, through the orifice O, in the form of a jet. Close the orifice O with the finger, and then raise the piston; a *vacuum* is formed beneath the piston.

Exp. 2. Close one end of a small tube with the fore finger, and then fill it with water; invert the tube so as not to spill any of the fluid: the water remains in the tube. Here the water would fall out of the tube by its weight, if the upward pressure of the atmosphere did not sustain

it. The finger, placed upon the top of the tube, takes off the pressure of the air from the upper surface of the water, while the upward pressure

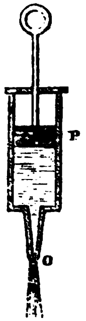


Fig. 7.

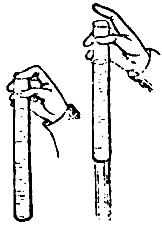


Fig. 8.

of the atmosphere upon the under surface of the water sustains the fluid in the tube in opposition to its gravity. Take away the finger, and then the water descends by its own weight; for in this case, the air presses upon the upper surface of the water, as well as upon its lower surface.

Exp. 3. Fill a very small-necked bottle with water; cautiously invert the mouth of the bottle: the water remains suspended in the bottle by the upward pressure of the atmosphere.

Fig. 9.

Exp. 4. Fill a wine glass with water, and cover the mouth with a piece of paper; place the hand over the paper, and invert the glass; take the hand carefully away: the water remains suspended in the glass by the atmospheric pressure.

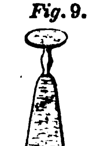


Fig. 10.

Exp. 5. The bent tube A B is closed at the extremity A, and open at B. Fill the tube with water or mercury, as shown in the figure, then the fluid will be supported in the branch A by the pressure of the air on the surface of the fluid at B. A tube of this kind, known by the name of *Cooper's Tube,* is frequently used in experimental chemistry.

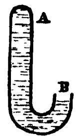


Fig. 11.

The *bird fountain* and the *fountain ink bottle* depend upon the same principle. In Fig. 12, A represents the liquid in the fountain, and B the liquid in the cup. As the liquid is taken from the cup, an equal portion descends from the fountain, to supply the place of that which is taken away.

Exp. 6. The common *sucker* affords a simple and beautiful illustration of the pressure of the atmosphere. Observe that the wetted

piece of leather, or sucker, is raised in the middle, by the string attached to that part; this forms a hollow space, or vacuum, between the central

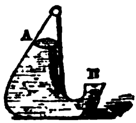


Fig. 12.

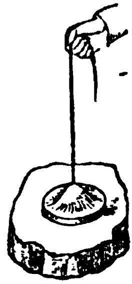


Fig. 13.

portion of the sucker and the stone; the pressure of the atmosphere, therefore, presses the stone upwards against the sucker. The stone falls the moment a hole is made in the central part of the sucker.

In this manner limpets stick with such force to the rocks; and on the same principle flies walk on the ceiling, for they have the power of forming their little feet into suckers.

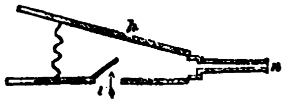


Fig. 14.

Exp. 7. Take a pair of common bellows; observe, while you raise the top board *h*, that the valve *v* opens, in consequence of the external air rushing in to fill up the void; and observe, while you depress the top board, that the valve *v* is closed, and the air is propelled through the nozzle *n* with considerable force, in consequence of the elasticity of the compressed air within the bellows.

Exp. 8. Take a glass tube, about 32 inches long, closed at one extremity; fill the tube with mercury, apply the finger to the open end, and immerse it in a cup of mercury; bring the tube to an erect position, as shown in the accompanying figure: a column of mercury about 30 inches high remains supported in the tube by the pressure of the atmosphere upon the surface of the mercury in the cup. The space in the upper part of the tube is a vacuum.

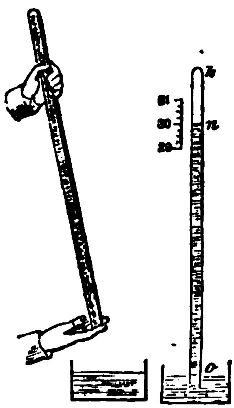


Fig. 15.

This remarkable experiment was first made by Torricelli, who was a pupil of the celebrated Galileo, and hence it has been called the *Torricellian experiment.*

8. The average pressure of the air is 15 lbs. per square inch.

The column of mercury which balances the pressure of the air is estimated from *o* to *n*, (see Fig. 15;) that is, it is equal to the height of the mercury in the tube above the level of the mercury in the cup. As this column of mercury balances the pressure of the air, so therefore the weight of the mercury in the tube is equal to the pressure of the air upon a surface equal to the internal section of the tube. (See HYDROSTATICS, Art. 15.) For example, let the internal section of the tube be 1 square inch, and the height of the column of mercury *o n* 30 inches; then there will be 30 cubic inches of mercury in the tube; now, 1 cubic inch of mercury weighs very nearly half a pound; therefore the weight of the mercury in the tube will be 15 pounds; but this weight of mercury balances the pressure of the air exerted on 1 inch of surface; therefore the pressure of the air upon 1 inch of surface is about 15 pounds.

The height of the column of mercury is not affected by the size of the tube; for if the section of the tube were 2 inches, in the place of 1, the weight of the mercury would be doubled; but the pressure of the air, in this case, would also be doubled, inasmuch as it would act upon 2 inches of surface, in the place of 1.

The pressure of the air will support a much longer column of water than of mercury; for water being about 13½ times lighter than mercury, the column of water must be 13½ times the length of the column of mercury to produce the same amount of pressure. (See HYDROSTATICS, Art. 25, Exp. 2.) Now, we have seen that it takes about 30 inches of mercury to balance the pressure of the air; therefore it will take 13½ times 30 inches, or about 34 feet of water, to balance this pressure; that is to say, upon an average, *the pressure of the air is able to sustain a column of water 34 feet high.* Hence it is that water cannot be raised higher than 34 feet by the common pump.

9. The pressure of the atmosphere on our bodies is essential to health; for it counterbalances the pressure of the fluids within us, and thereby gives a spring and elasticity to their motion. When the weight of the air is taken away from any part of our bodies, the internal pressure of the blood causes those parts to swell out; hence it is that persons experience an unpleasant sensation when they ascend a high mountain.

The Barometer.

10. The Torricellian experiment not only exhibits the principle of the barometer, but also shows the manner in which it is made. It has been found that the pressure of the atmosphere is not always the same; sometimes it will support a column of mercury equal to 31 inches, whereas at other times it will only support a column of 28 inches. Now, the barometer is an instrument contrived to measure the weight or pressure of the air at any time; in order, therefore, to enable us to see the height of the mercury in the tube, there is a scale placed at the upper end *n* (see Fig. 15) giving the distance from the surface of the mercury in the cup.

If a barometer be taken to the top of a mountain, the mercury in the tube will fall; because, as we ascend above the level of the sea, the pressure of the atmosphere becomes less and less. In this way the barometer is sometimes used to determine the height of mountains. It is also used as a weather gauge; for, when the air is dense and heavy, the mercury in the barometer stands high; and in such states of the atmosphere we generally have fine, clear weather; but, on the contrary, when the air becomes rare and light, the mercury in the barometer falls, and then we are likely to have rainy or stormy weather.

A barometer tube is sometimes attached to air pumps, for the purpose of indicating the degree of exhaustion produced in the receiver.

The Siphon.

11. This instrument is used for drawing off liquids from vessels which it would be inconvenient to move from the place where they stand. It simply consists of a bent tube B A C having one branch A B longer than the other one A C.

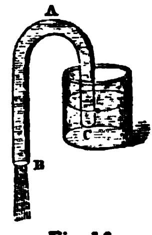


Fig. 16.

Experiment. — Fill the bent tube B A C with water; place a finger on B, and another on C; invert the tube, and immerse the short leg in the water; take away the finger: then the water immediately runs in a stream from the orifice B. Hold the vessel in such a position as to bring the orifice B on a level with C: the water then ceases to flow.

The principle of the siphon is exceedingly simple: the column of water A B being longer, and of course heavier, than the column A C, the fluid necessarily flows in the direction of the greater pressure. At the same time, it is to be observed that the pressure of the atmosphere, tending to force the water up the leg C A, is the same as that which is tend-

ing to force the water up the leg B A, so that the one exactly balances the other, and therefore the water is left to descend by its excess of gravity in the leg A B.

Intermitting Springs.

12. The principle of the siphon enables us to explain the nature of intermitting springs, or those springs which only flow at stated periods. A D E represents a cavity in a hill, which becomes gradually filled with water from the rain and snow draining through the porous earth or rocks; A B C is a siphon-shaped fissure proceeding from this cavity; as the water collects in the cavity, it rises higher and higher in the leg A B until it reaches the level K B, when it begins to flow through the long leg B C; and as the water continues to rise in the cavity, the discharge at C will also increase until the water flows in a continuous jet. Now, on the principle of the siphon, the water will continue to flow from C until the water in the cavity sinks to the level of A E, when the air will rush into the siphon A B C; and then the water will not flow again until it has reached the level K B, so that the spring will appear to have regular intervals of repose.

Fig. 17.

ELASTICITY OF THE AIR.

13. This property of the air has already been explained in Hydrostatics, Art. 4, and also in Exp. 1, Art. 4, of the present treatise. The following simple experiments will still further elucidate the subject.

EXPERIMENTS.

Exp. 1. Introduce water into a large, wide-mouthed bottle; fit a small glass tube, open at both ends, to the mouth of this bottle, by means of a perforated cork, as shown in the figure; blow through the tube so as to increase the quantity of air in the bottle: after withdrawing the mouth the water will rise in a jet, owing to the expansive force of the condensed air in the bottle.

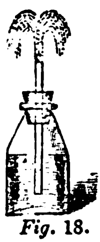


Fig. 18.

Exp. 2. Fig. 19, A is a two-necked bottle containing some water; B is an inflated bladder tied to one of the mouths of the bottle; *a b* is a long glass tube reaching nearly

to the bottom of the bottle; this tube is fitted air-tight to the mouth of the bottle by passing through a perforated cork. By compressing the air in the bladder the water will rise up the tube, from the elasticity or pressure of the condensed air in the bottle.

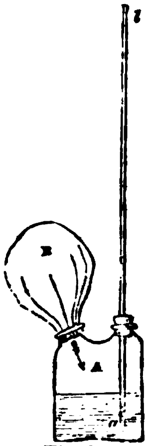


Fig. 19.

Exp. 3. The following instructive experiment affords an amusing illustration of the elasticity of the air, as well as of the nature of specific gravity. Fig. 20, A is a wide-mouthed bottle, nearly filled with water, in which some hollow glass figures having a hole in one foot, called *bottle imps*, are placed so as to float near the surface when filled with air; a piece of bladder is tied over the mouth of the bottle so as to exclude the external air. Press the bladder with the fingers; the figures descend in the water; remove the pressure, and they ascend; and so on. By thus alternately raising and depressing the fingers, the little figures may be made, as it were, to dance up and down the fluid. Here the pressure on the bladder, by compressing the air beneath it, produces a pressure on the surface of the water, and this causes a small portion of the liquid to enter the hollow figures, which increases their specific gravity, and in this case, therefore, they descend; on the contrary, when the pressure is removed from the bladder, the air within the figures regains its original bulk, and then they ascend. On this principle fishes are enabled to rise and fall in the water: they have a little air bladder within their bodies, which they contract when they wish to descend, and expand when they wish to rise.

Fig. 20.

Exp. 4. Invert a small bottle, and introduce so much water as will just cause it to float on the surface of the fluid; gently depress the bottle to about the middle of the water, without allowing any of the air to escape: the bottle sinks to the bottom, where it will remain. In fact, the bottle will only float near the surface. Here, when the bottle is depressed, an additional portion of water enters it, in consequence of the increased depth of the fluid; by this means the specific gravity of the bottle is increased, and hence it sinks.

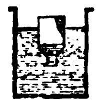


Fig. 21.

Exp. 5. The *popgun* affords a good illustration of the elasticity of the air.

14. The elasticity or pressure of air increases with the decrease of the space which it is forced to occupy.

In order to explain this law, let P represent a piston compressing the air in the cylinder A B C D; suppose the surface of the piston to be one square inch, and that the atmosphere exerts a pressure of 15 lbs. per square inch; now let an additional load or pressure of 15 lbs. be laid on the piston, then the piston will descend to *a b*, and the air beneath it will be reduced to one half its original volume — that is to say, *air under a pressure of two atmospheres is reduced to one half its original volume*. Again, let twice 15 lbs. be laid upon the piston, then it will descend still farther, and the air beneath it will be reduced to one third its original space — that is to say, *air under a pressure of three atmospheres is reduced to one third its original space;* and so on. Thus it appears that, as we increase the pressure applied, so we in the same proportion reduce the space occupied by the air. And it will be readily understood that the pressure which compresses any portion of air is the measure of its elasticity or tendency which it has to expand.

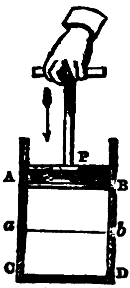


Fig. 22.

This law of elasticity was first proved by Marriotte, in the following manner: —

Experiment. Take a bent tube H E A B closed at B; introduce a little mercury, so as to make it stand at the same level E A in both legs of the tube; let the space A B occupied by the enclosed air be divided into equal parts; pour mercury into the tube until the volume of air in A B is reduced to C B; then it will be found that when C B is one half A B, the column of mercury D H producing this compression is about 30 inches, or a column of mercury which balances the pressure of the atmosphere; that when C B is one third A B, or when the volume of air is reduced three times, the column of mercury D H is twice 30 inches, and so on; thereby proving the law of elasticity just explained.

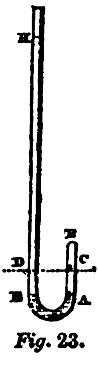


Fig. 23.

Variation in the Density of the Air.

15. It has been already mentioned, Art. 10, that as we rise above the earth's surface the air becomes thinner and thinner, or less and less dense this is a necessary consequence of the law of elasticity. The following remarkable relation between the density of the air and its height above the level of the sea deserves to be especially noticed: as the elevation above the level of the sea increases in arithmetical progression, the density or pressure of the air decreases in geometrical progression. Thus, if the pressure of the air at the level of the sea be, on an average, 15 lbs.

per square inch, then at the height of about 3½ miles * it has a pressure of ½ of 15 lbs.; at the height of 2 times 3½ miles it has a pressure of ¼ of 15 lbs.; at the height of 3 times 3½ miles it has a pressure of ⅛ of 15 lbs.; and so on. It will be seen that for every successive 3½ miles which we ascend, the pressure of the air is always the half of what it is at the preceding elevation. This law would be strictly true, if the atmosphere were every where of the same temperature and contained the same quantity of moisture.

Relations of Air to Heat.

16. When a body is heated, it expands or becomes greater in bulk; in this way, heat rarefies bodies, and causes them to become specifically lighter.

Elastic fluids, such as air, are more susceptible of this action of heat than either solids or liquids. The air over a common fire becomes rarefied by the heat, and being thus rendered specifically lighter than the surrounding atmosphere, it ascends up the chimney, and its place is supplied by the current of air which rushes towards the fireplace from all parts of the room, especially from the openings, or apertures in windows and doors. Thus a fire creates an artificial wind. On the same principle, the unequal distribution of heat over the earth produces on a great scale the various currents of air or winds, which are every where felt.

17. The following simple experiments will render this property of air more apparent.

Experiments.

Exp. 1. Partially fill a bladder with air, and after tying its mouth, place it near a good fire: the air within the bladder expands and completely fills it.

Exp. 2. Invert a wine glass in a basin; gently pour hot water into it: bubbles of air escape from the wine glass, in consequence of the expansion of the air by the heat.

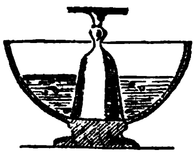


Fig. 24.

Exp. 3. Throw a piece of burning paper into a wine glass, and while the paper is still burning, forcibly close the mouth of the glass with the hand; after a few seconds, the glass will be found to stick to the hand with considerable force. Here the heat expels nearly the whole of the air in the glass, by causing it to expand · after the air in the glass cools, it contracts, and then the

* More exactly, 3.42 miles.

pressure of the external air upon the outside of the glass becomes greater than the pressure of the rarefied air within the glass.

Fig. 25.

Exp. 4. Cut a piece of paper in the form of a spiral, as in Fig. 26; run a thread through the centre *c;* suspend the paper by this thread, and it will have something like the form of a corkscrew; bring it over the flame of a candle: the suspended paper turns round in one certain direction. Here the heated air about the candle ascends, and by striking against the surface of the paper, causes it to revolve on the same principle as a toy windmill.

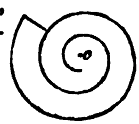


Fig. 26.

The Exhausting and Condensing Syringe.

18. This instrument is used for two purposes, viz., for exhausting air from a vessel, and also for compressing air into a vessel. A section of this instrument is represented in the accompanying figure. P is a solid piston, working air tight in a cylinder: P S is the piston rod, working through an air tight collar S, so that as the piston rod moves up and down through this collar, no air shall be allowed to pass through it into the cylinder; V is a valve, or little door, opening outwards; O is an open aperture leading to the vessel A, from which air is to be exhausted. Let us now see how this instrument *exhausts the air* from vessels. First of all, the piston P is drawn to the top of the cylinder, then the glass globe A, having a stop cock B attached to it, is screwed on to the pipe O, and the stop cock B is opened. The instrument being in this state, force down the piston; then the air beneath it is driven out of the cylinder, through the valve V, while the air in the globe expands and fills the upper part of the cylinder. Raise the piston; then the valve V is closed by the pressure of the external air, and a vacuum is formed beneath it; but the moment the piston P passes the orifice O, the air rushes from the bottle and fills up the void formed in the cylinder. When the piston is forced down again, a quantity of air, equal to the volume of the cylinder, is again driven out; so that after this operation has been repeated for about a dozen times, the air in the bottle becomes so attenuated or rarefied, as almost to approach a vacuum. After the exhaustion is completed, the cock B is closed, and the globe is unscrewed from the cylinder.

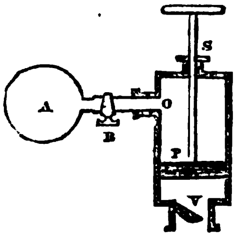


Fig. 27.

Let us now see how the instrument acts as *a condenser of air*. First of all, the piston P is drawn to the top of the cylinder; then the bottle A, into which the air is to be compressed, is screwed on to the pipe Q, the pipe O, in this case, being left completely open. Force down the piston; then the air beneath it is driven through the valve V into the bottle. Raise the piston; then a vacuum is formed beneath it, but at the same time the valve V is kept shut by the pressure of the air in the bottle, so that no air can escape from it; now the moment the piston P passes the orifice O, the external air rushes into the cylinder and fills it. In the next downward stroke, the air beneath the piston is again forced into the bottle; so that at every downward stroke a quantity of air, equal in volume to the cylinder, is forced into the bottle. When the air has been sufficiently condensed, the cock B is closed, and the bottle is unscrewed from the cylinder. The bottles used for holding condensed air are usually made of metal.

The Air Pump.

19. The air pump is used for withdrawing the air from large glass vessels, called receivers, in which experiments are performed. The accompanying figure represents a common air pump, with a single barrel. P is a piston, working air tight in the barrel or cylinder R *e*; this piston has a valve, or little door in it, opening upwards, which allows the air to escape outwards, but does not allow any air to pass inwards; V is a valve, placed at the bottom of the cylinder, which also lifts upwards; *e* D E O is a pipe, which connects the cylinder with a flat, polished plate B, on which the receiver A stands; the bottom of this receiver is ground flat, so that it may fit perfectly air tight to the plate when a little lard is rubbed over it; K is a stop cock; *e* is a nut, which, being unscrewed, allows the external air to enter the receiver; N M is the mercury gauge for indicating the degree of exhaustion produced in the receiver A; this gauge acts on the same principle as the Torricellian tube. (See Art. 10.)

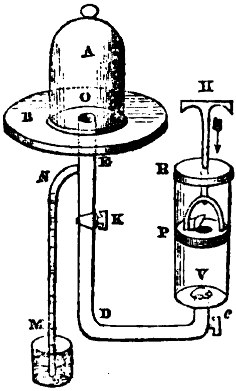


Fig. 28.

Let us now see how the pump acts. The receiver A, from which the air is to be withdrawn, being carefully placed upon the plate with a little clean lard rubbed upon it, the stop cock K is opened, and the nut *e* is screwed tightly up. The instrument being in this state, the piston

P is worked rapidly up and down, until a sufficient degree of exhaustion is produced in the receiver, which is always shown by the height N M at which the mercury stands in the gauge; the stop cock K is then closed in order to cut off any further communication with the pump. At each downward stroke of the piston, the valve in it opens, allowing the air beneath it to escape, while the valve V is closed; on the contrary, at each upward stroke, the valve in the piston is closed by the pressure of the external air, while the air in the receiver lifts up the valve V, and fills up the vacuum which would otherwise be formed beneath the piston. Thus a certain portion of the air remaining in the receiver is always withdrawn at every double stroke, so that by continuing the process, the air in the receiver at length becomes so rarefied as almost to approach a vacuum.

To show the use of the gauge, let us suppose that the column of mercury in the barometer stands at the height of 30 inches, and that the column M N in the gauge is 28 inches; then the deficiency, 2 inches, is due to the elasticity of the air in the receiver; and, therefore, since 2 is the $\frac{1}{15}$ part of 30, the elasticity of the air in the receiver will be the $\frac{1}{15}$ part of the elasticity of the external air.

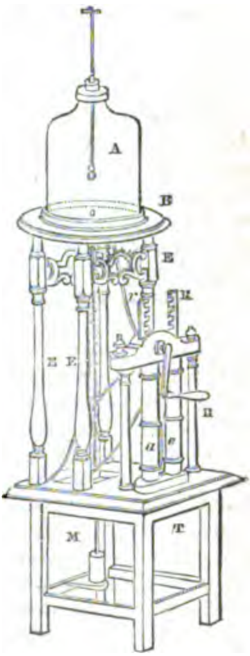


Fig. 29.

20. In order to facilitate the exhaustion, air pumps are usually made with two cylinders, so that while one piston is ascending, the other is descending, and thus the process of exhaustion is continually kept up. The pistons, in these pumps, are moved by a toothed wheel, which is made to act upon racks formed upon the piston rods. The accompanying figure represents an air pump of this kind. *a* and *e* are the two barrels; *r* and R the racks formed on the piston rods; H is the handle or winch, which gives motion to the toothed wheel placed between the racks, so that a back and forward motion being given to this handle, an up and down motion is communicated to the pistons; A is the receiver, standing on the plate B; T is a table, on which the machine is fixed; E E are the pillars supporting the plate B; M is the mercury gauge; and so on to the other parts of the machine, as already described.

EXPERIMENTS PERFORMED WITH THE AIR PUMP.

Exp. 1. To fasten the hand to a glass by means of the atmospheric pressure. A B is a small glass, open at both ends, about 3 inches diameter. Place this glass over the hole of the air pump plate; lay your hand tightly over the top A; turn the handle of the pump for a few times: the hand becomes fastened to the glass by the pressure of the air.

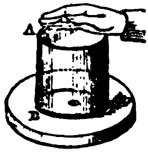


Fig. 30.

Exp. 2. To burst a bladder by the pressure of the atmosphere. Tie a piece of thin bladder, moistened in water, over one end of the glass used in the last experiment; after the bladder has become dry, it will be perfectly tight. Place the glass on the plate of the air pump; then, after a few turns of the handle, the bladder will burst with a loud report, from the pressure of the atmosphere.

Fig. 31.

Exp. 3. A and B are two brass cups, called *Magdebourg hemispheres*, which exactly fit each other at the edges, so that when they are brought together they form a sphere; C is a pipe, with a stop cock leading into the interior of the cup B. Put a little lard on the edges of the cups, and bring them together; screw them by means of C to the plate of the air pump; exhaust the air from the inside; turn the stop cock C, and unscrew them from the pump; screw the handle D on at C: the cups being now pressed together by the atmosphere, will require a considerable force to separate them.

Fig. 32.

Supposing the air to be completely exhausted from the inside of the cups, and that their section contains 10 square inches; then the atmospheric pressure on each square inch will be about 15 lbs., and therefore the whole pressure of the atmosphere, tending to keep the cups together, will be 10 times 15 lbs., or 150 lbs. In this case, therefore, it would require a weight of 150 lbs. to separate the cups.

Exp. 4. Tie the mouth of a little flaccid bladder; place it beneath the receiver of an air pump; exhaust the air from the receiver: the air within the bladder gradually expands (the pressure of the air within the receiver being removed) until the bladder becomes completely distended; allow the external air to enter the receiver by turning the screw K, (see Fig. 28:) the bladder becomes shrivelled up as at first.

Exp. 5. Put a glass bulb B, blown at the end of a tube, into a bottle of water, as shown in the figure; place them beneath the receiver of the air pump; exhaust the air from the receiver; then, as the exhaustion

goes on, the air in the bulb will rise in bubbles through the water, so that the air in the bulb will become rarefied, as well as that which is in the receiver. When the bubbling has ceased, allow the external air to enter the receiver: the water, from the atmospheric pressure, rushes into the bulb, and nearly fills it.

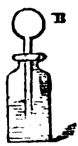


Fig. 33.

Exp. 6. A small bottle containing a bubble of air is sunk in a deep vessel filled with water, as in the accompanying figure; place the vessel beneath the receiver of the air pump, and exhaust the air: the bottle rises in the water; allow the air to enter the receiver: the bottle sinks to the bottom; and so on. For an explanation of this experiment, see Exp. 3, Art. 13.

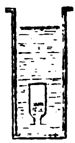


Fig. 34.

Exp. 7. A represents a receiver, open at the top, but which is closed air tight by the perforated cork *k*, and barometer tube *a b*; *c* is a cup of mercury, into which the open extremity of the tube *a b* nearly dips. Exhaust the air from the receiver; depress the tube *a b*, so that its extremity may be immersed in the mercury; allow the external air to enter the receiver: the mercury mounts up the tube *a b* very nearly to the height of 30 inches.

This experiment clearly shows, that mercury is sustained in the barometer tube by the pressure of the atmosphere alone, and not by any imaginary principle, such as *suction* or *nature's horror of a vacuum*, as the ancient philosophers supposed. (See Art. 10.)

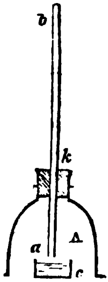


Fig. 35.

Exp. 8. The accompanying figure represents a piece of apparatus for producing *a fountain in a vacuum*. A brass pipe *a e* passes through a smooth plate B; this pipe has a stop cock at C, and a jet at its upper extremity *e*; R is a tall glass receiver, standing on the plate B, from which the air may be withdrawn by screwing the extremity *a* of the pipe into the hole of the air pump plate. When the air has been withdrawn from the receiver R, it becomes fixed to the plate B; the stop cock C is then closed, and the apparatus is unscrewed from the pump. Now plunge the extremity *a* of the pipe into a vessel of water; open the cock C: the water rises in a beautiful jet within the receiver.

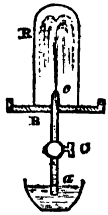


Fig. 36.

Exp. 9. To transfer a liquid from one bottle to another. The bottle A contains some colored liquid; the bent tube A *a b* B, reaching nearly the bottom of the bottles, is fitted air tight to the neck of the bottle A, but passes freely through the neck of the

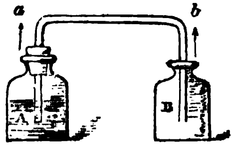


Fig. 37.

other one. Place this apparatus under the receiver of the air pump, and exhaust the air: the liquid passes from A to B, from the elasticity of the air in the former. Now admit the air into the receiver: the liquid returns to the bottle A.

Exp. 10. Place a shrivelled apple beneath the receiver of the air pump; exhaust the air: the apple gradually becomes plump and rounded, from the expansion of the air within it. Admit the air into the receiver: the apple becomes shrivelled up as at first.

Exp. 11. Place a glass of beer beneath the receiver; exhaust the air from it: the beer foams up and appears quite brisk, from the escape of carbonic acid gas which is in it. Now admit the air into the receiver; the bubbling ceases, and the beer appears flat and dead.

Exp. 12. To show that air is contained in the pores of solid substances. Put a piece of beet root, or any porous substance, into a vessel of water, and place it beneath the receiver of the air pump; then, upon exhausting the receiver, the beet root becomes covered with little globules of air, which at once disappear when the external air is readmitted into the receiver.

Exp. 13. The pressure of the atmosphere will force mercury through the pores of wood. The metal plate *a a* is made to fit the top of a receiver; this plate has a hole passing through it, into which is fitted a wooden cup *b*. Place the plate and cup upon the top of the receiver; fill the cup *b* with mercury, and exhaust the air from the receiver: a fine shower of mercury falls into the receiver.

Fig. 38.

Exp. 14. In highly rarefied air, *a feather falls as quickly as a guinea.* A is a long receiver, placed upon the plate of the air pump; *a* is a metal plate covering the top of the receiver; *s s* are two flaps, suspended from the plate *a*, on which the feather and coin are laid; the wire *r* passes through the plate, and carries a stage, with two notches in it, at the lower end, for supporting the flaps. Having turned up the flaps, place the feather and coin upon them; exhaust the air from the receiver; turn the wire *r* until the flaps slip down through the notches in the stage; the feather and the coin drop at the same instant, and, falling with equal velocities, they reach the bottom of the receiver in the same time.

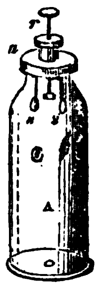


Fig. 39.

Exp. 15. Air resists the motion of machinery. Here *a* and *b* are two wheels of the same size, turning on separate axes; but the vanes of *a* cut the air edgewise, while the vanes of *b* strike it breadthwise; by suddenly raising or depressing the rod *d e*, a rapid rotatory motion is given to the two wheels; this rod passes through an air tight stuffing box *e*, placed at the top of the

receiver R. Let motion be given to the wheels when the receiver contains air: the wheel *b* stops much sooner than *a*. Now exhaust the receiver, and then set the wheels in motion; the wheels continue to move for a much longer time than they did in the air; and moreover they stop at the same instant.

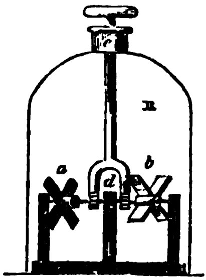


Fig. 40.

Exp. 16. Smoke falls in rarefied air. Blow out a candle, and put it under a receiver; the smoke rises to the top. Partially exhaust the air from the receiver; the smoke descends in the fluid specifically lighter than itself.

Exp. 17. Weighed in the air, an ounce of cork is heavier than an ounce of lead. Balance a piece of cork and lead in a small pair of scales; place them beneath the receiver, and exhaust the air; the scale on which the cork is put plainly preponderates. This shows that the air exerts a greater force of buoyancy on the cork than it does on the lead.

Exp. 18. Sound is not transmitted through highly rarefied air. To show this important fact, a bell must be placed upon some bad conductor of sound, such as wool or horse hair, to separate it from the plate of the air pump; and the apparatus must be so contrived that the clapper can be made to strike the bell without allowing the external air to enter the exhausted receiver. In the accompanying figure, R represents the receiver; *a* the bell, standing on the horse hair cushion *g*; *c b* the clapper, which may be agitated by the lever *h*, attached to the rod *h k*, passing through the stuffing box *s* at the top of the receiver. Before the air is withdrawn from the receiver, let the clapper be agitated, to show that the sound of the bell is distinctly transmitted through the air in the receiver. Now let the air be exhausted, and, during the process, let the clapper be agitated from time to time; the sound becomes more and more feeble, until it ceases altogether.

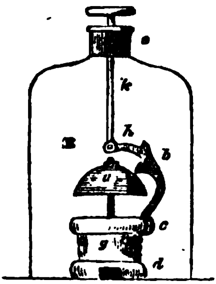


Fig. 41.

Exp. 19. Water boils at a much lower temperature in rarefied air. Place some hot water beneath the receiver, and exhaust the air: the water boils violently. Admit the air into the receiver; the ebullition in a moment ceases; and so on.

Hence it is that water boils at a much lower temperature at the top of a mountain than it does at the level of the sea.

PNEUMATIC AND HYDRAULIC MACHINES.

The Common Pump.

21. The accompanying figure represents a section of the common suction pump. A C is a cylinder or barrel, in which a piston P is moved up and down by means of a piston rod R, attached to the extremity of the lever R H of the first kind. In the piston is a valve *v* lifting *upwards*; and at the bottom of the barrel is another valve V, also lifting *upwards*. A B is a pipe, passing from the bottom of the barrel into the well from which the water is to be raised.

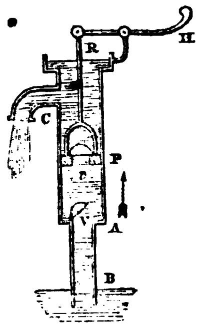


Fig. 42.

The first effect of the motion of the piston is to clear the barrel and pipe of air; at the first upward stroke of the piston, the air in the pipe A B expands and enters the barrel, and being thus rarefied, exerts less pressure upon the water in the pipe; the consequence is, that the pressure of the external air forces a portion of water into the pipe. Now, in the downward stroke of the piston, the valve V closes, while *v* opens and allows the air in the barrel to escape, so that there is now a much less quantity of air in the pipe than there was at first; at the second upward stroke, therefore, the air in the pipe is still further rarefied, and thus an additional quantity of water is raised in the pipe by the pressure of the external air; proceeding in this manner, after a few strokes, the water is raised into the barrel, and then another kind of action takes place.

In a downward stroke of the piston, it plunges amongst the water in the barrel of the pump; the valve V closes, and the valve *v* opens, and allows the water to pass to the upper side of the piston. In an upward stroke, the valve *v* closes, and the valve V opens, and, by the pressure of the atmosphere, the water follows the piston in its ascent, whereas the water above the piston is pushed before it, and thus the fluid is discharged in a stream at the mouth C of the pump; and so on to any number of strokes.

If a perfect vacuum were formed by the piston as it ascends, the water would be raised, on an average, to the height of 34 feet above the level of the water in the well, which is the height of a column of water calculated to balance the average pressure of the atmosphere.

The Common Forcing Pump.

22. This pump raises water from the well into the barrel, on the principle of the suction pump just described, and then the pressure of the piston on the water elevates it to any height that may be required.

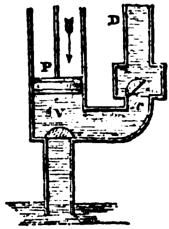


Fig. 43.

Here P is a solid piston, working up and down in a barrel; V a valve, lifting upwards, placed at the top of the pipe descending into the well; *v* a valve, also lifting upwards, placed in a pipe D, which conveys the water to the cistern.

In a descending stroke of the piston, the valve V closes, and the valve *v* opens, and the water, being pressed before the piston, is forced up the pipe D to the higher level required; on the contrary, in an ascending stroke, the valve *v* closes by the pressure of the external air and the water in the pipe D; the valve V opens, and the water rises into the barrel of the pump by the pressure of the atmosphere on the water in the well; and so on to any number of strokes.

The Forcing Pump with an Air Chamber.

23. This engine merely differs from the preceding one by having an air chamber *e c v* connected with the vertical pipe D. This air chamber is a closed vessel, having the pipe D descending into it, and a valve *v* opening and closing its communication with the barrel of the pump. When the piston P descends, the water is forced through the valve *v* into the air chamber, so that as soon as the water rises above the lower orifice of the pipe D, the air in the upper part of the chamber is contracted or compressed; and this compression of the air causes it to exert a continuous pressure upon the surface of the water in the chamber, which forces the fluid up the pipe D, and thus a constant discharge into the cistern is sustained. In the common forcing pump, the water is only discharged at each downward stroke of the piston, whereas, in the present case, the pressure of the air in the chamber sustains the discharge through the vertical pipe D, during the intervals taken up by the upward strokes of the piston.

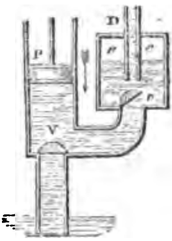


Fig. 44.

The great defect of this engine is as follows: after the pump has been some time in action, the air in the chamber becomes absorbed by the water passing through it, so that at length it is found that nearly all the air at first in the chamber has passed away with the water discharged by the pump.

Double-acting Pump.

24. This pump is designed to remedy the defect of the preceding one. It is simply a double-acting forcing pump, similar in its construction to that described in Art. 22. P is a solid piston, which moves up and down in a cylinder; the rod of this piston passes through a stuffing box at S for the purpose of keeping the cylinder air tight. On the opposite sides of the cylinder are two pipes, A B and C D; where A B descends into the well, and C D conveys the water to the reservoir. There are four valves, *a*, *b*, *e*, *c*, opening and closing, as the case may be, the communication of these pipes with the cylinder. These valves all lift in the same direction, that is, to the right. Suppose the cylinder and pipes filled with water; then, in an upward stroke of the piston, the valves *a* and *e* are opened, and *c* and *b* are closed; the water is forced by the piston through the valve *e*. and then up the vertical pipe C D; at the same time the water, by the atmospheric pressure, rises up the pipe A, and opening the valve *a*, follows the piston in its ascent: on the contrary, when the piston descends, the valves *a* and *e* are closed, and *c* and *b* are opened; the water is then forced through the valve *c*, up the vertical pipe C D, and the water from the well enters the cylinder through the valve *b*, and follows the piston in its descent; and so on to any number of strokes.

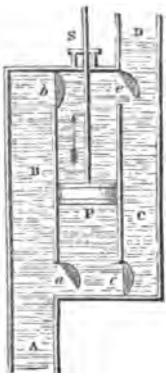


Fig. 45.

The Fire Engine.

25. This engine is simply a combination of two forcing pumps, having a common air chamber, H, and the same suction pipe F descending to the water intended to supply the engine. (See Art. 22.) The beam A B, turning on its centre of motion K, works the two pistons C and D; so that while the one is descending, the other is ascending, thereby keeping up a continuous flow of water into the air chamber H. A flexible tube *e* L of leather, called *a hose*, is attached to the discharge pipe, to enable the engineer to direct the stream of water

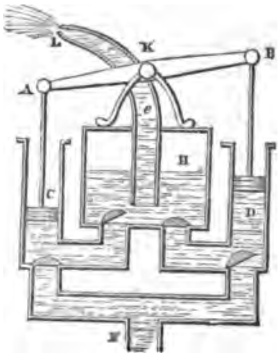


Fig. 46.

upon any particular spot. The degree of compression attained by the air in the chamber regulates the velocity with which the water is projected from the nozzle L of the hose.

If, for example, the air be compressed to one half its original bulk, then it will act upon the surface of the water in the chamber with a pressure equivalent to that of the atmosphere, and the water would be raised in the pipe *s* to the height of about 34 feet, or it would be projected from the nozzle L with a velocity equal to that which a body would acquire in falling freely, by the force of gravity, from this height. (See Art. 41.)

The Hydrostatic Press.

26. The principle on which the power of this engine depends has been explained in the treatise on Hydrostatics, Art. 11; it only remains, therefore, for us to notice some contrivances connected with its operation. H C is a lever of the second kind, turning on the fixed centre C, which works the piston *p* of the small cylinder; P is the large piston, which, by ascending, compresses the material S placed between the press boards; A is a pipe proceeding from the bottom of the small cylinder to a cistern of water; V is a valve lifting upwards, placed at the top of this pipe; *v* is a valve, opening to the left, placed in the pipe which connects the two cylinders.

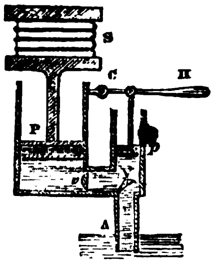


Fig. 47.

In a descending stroke of the piston *p*, the valve V closes, and the valve *v* opens, and the water is forced into the large cylinder, which causes the piston P to ascend and compress the material S; on the other hand, in an ascending stroke of the piston *p*, the valve *v* closes by the pressure of the water in the large cylinder; the valve V opens and allows a fresh supply of water to enter the small cylinder; and so on, as in the common forcing pump described in Art. 22.

Hydraulic Ram.

27. This elegant and useful contrivance for raising water may be employed with advantage where there is an abundant supply of water with only a small descent.

The action of this engine depends upon the great force which is produced whenever a body in motion suddenly meets with an obstacle. A body of water acquires motion in its descent through an inclined

pipe A; and the outlet *k*, upon being suddenly closed, allows the motion accumulated in this body of water to expend itself in forcing some of the fluid in the pipe B into an air chamber *d*, whence it is raised by the pressure of the air in the chamber to any proposed elevation.

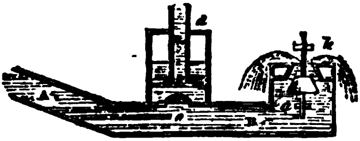


Fig. 48.

A is an inclined pipe conducting a stream of water from a reservoir; B a horizontal portion of this pipe, having a valve *e* opening into the air chamber *d*; *a* is a heavy valve which closes, when it is lifted upwards, the outlet of the water at *k*; this valve is so heavy that it descends in the quiescent fluid by its own weight, thereby opening the outlet at *k*, at the same time it is capable of being lifted up by the impetus of the water as it rushes out of the opening *k* with the velocity acquired in descending the inclined pipe A.

The valve *a* being first opened, the water, rushing out of the orifice *k*, at length acquires a velocity sufficient to drive the valve *a* upwards, thereby closing the orifice *k*; the current of water through *k*, being thus suddenly checked, expends the motion accumulated in it in forcing some of the fluid through the valve *e* into the chamber *d*. Now, when the water has become quiescent, the heavy valve *a* descends by its own weight and opens the orifice *k*; the water again rushes out of the orifice, and so on as already described.

Hero's Fountain.

28. The jet in this fountain is produced by the force of compressed air. *a* and *g* are two vessels united by means of pipes; the pipe *e f*, proceeding from the basin *n o*, descends nearly to the bottom of the lower vessel *g*; the pipe *h k*, passing from the top of the vessel *g*, nearly reaches the top of the vessel *a*; the jet pipe *d c* dips into the water in the vessel *a*, and rises above the basin *n o*. Let us now see how the fountain acts. The jet cock *b* being taken off, water is poured through the pipe *d* into the vessel *a* until it reaches the level *l m*; the dish *n o* is then filled with water, which, descending through the pipe *e f*, compresses the air in the vessels *g* and *a*; the stop cock *b* being now opened, the compressed air forces the water up the pipe *d c*, and thus the jet *c* is produced.

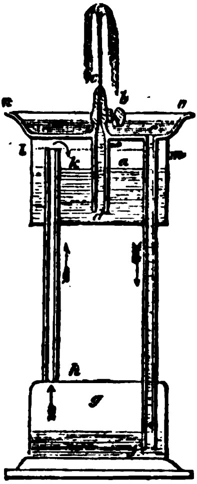


Fig. 49.

The Siphon Fountain.

29. The action of this fountain depends upon the principle of the siphon. Its construction is as follows: A is a glass receiver which fits closely to the plate B, through which two tubes *n m* and *s r* pass; the lower extremity *n* of the tube *n m* is immersed in water, and its upper extremity *m* rises within the receiver A; the lower extremity *s* of the tube *r s* descends below the surface of the water in the vessel *n*. To show the action of the fountain, invert the apparatus, and pour a little water through the tube *s r* into the receiver; close the aperture *s* with the finger, and place the apparatus in the position shown in the figure. Now, as the column of water in *r s* is longer than it is in *n m*, on the principle of the siphon, Art. 11, the water flows from *s*; but this occasions the water to fall in the receiver A, and hence the air in the receiver is rarefied; the pressure of the external air on the water in the vessel *n* forces the fluid up the tube *n m*, and thus a jet is formed within the receiver.

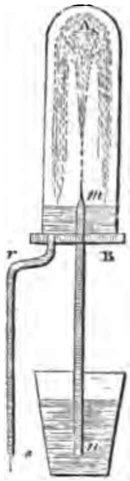


Fig. 50.

DIFFUSION OF GASES.

30. By this property is meant the tendency which airs or gases have to intermix with each other, without regard to their densities.

EXPERIMENTS.

Exp. 1. Take a bottle of carbonic acid gas, and invert a similar bottle of common air over it; then after a few minutes the carbonic acid gas will be equally diffused through the two vessels. Here the carbonic acid gas, which is $1\frac{1}{2}$ times heavier than common air, rises into the upper vessel in opposition to its gravity.

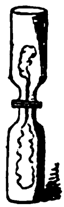


Fig. 51.

Exp. 2. Tie a piece of bladder over one end of a wide tube, fill it, over water, with hydrogen gas, and allow the tube containing the gas to stand for a few minutes. The water will gradually rise in the tube, apparently in opposition to gravity. Here, from the principle of diffusiveness, the hydrogen, being thinner than atmospheric air, escapes from the tube through the fine pores of the bladder more rapidly than the external air enters into it; the consequence is, that the pressure of the atmosphere forces the water up the

tube to fill the void which would otherwise be formed. In this experiment the diffusiveness of gases appears to act on a similar principle to that of endosmose and exosmose, explained at page 90.

31. The principle of the diffusiveness of gases is of vast importance in the economy of nature. For example, atmospheric air is chiefly a mixture of two gases, oxygen and nitrogen; but they are so completely diffused in the atmosphere, that every where we find them mixed in the same relative proportions.

LIQUEFACTION OF GASES.

32. Some gaseous bodies, when under great pressure and cold, are found to assume the liquid form: for example, carbonic acid gas becomes a liquid when subjected to the pressure of about forty atmospheres;* and chlorine gas becomes a liquid at a much lower pressure. But there are some gases, such as atmospheric air, which have hitherto resisted all attempts to liquefy them; such gases are called *permanently elastic fluids.*

ACOUSTICS, OR THE SCIENCE OF SOUND.

33. The atmosphere is the usual medium through which sound is conveyed to the ear.

(1.) Sound is heard when any sudden shock or impulse occurs in a body having communication, through the air or otherwise, with the ear.

Common instances of a single impulse are, the blow from a hammer, the clap of the hands, the crack of a whip, a pistol shot, or any explosion.

(2.) Impulses quickly repeated cannot be separately attended to by the ear; and hence they appear as one continued sound, of which the pitch or tone depends on the number

* Carbonic acid has even been brought to the solid form.

occurring in a given time: all continued sound is but a repetition of impulses.

If a wheel with teeth be made to turn, and to strike a piece of quill with every tooth, it will, when moved *slowly*, allow every tooth to be seen and every blow to be separately heard; but increase the velocity, and the eye will lose sight of the individual teeth, and the ear, ceasing to perceive the separate blows, will at last hear only a smooth, continuous sound, called a *tone*, of which the character will change with the velocity of the wheel.

(3.) When sonorous bodies (such as glass, bell metal, the string of a violin) are struck, a tremulous or vibratory motion takes place in the body; and this vibratory motion, being impressed upon the air, is transmitted to the drum of the ear, producing the sensation of sound. The following simple experiments show that sonorous bodies have this property: —

Experiments.

Exp. 1. If a bell be struck, its tremulous motion may be felt by gently touching it with the finger. When the finger is pressed against the bell, the sound is stopped, because the vibrations of the bell are interrupted.

Exp. 2. Attach a small piece of cork by a string to a bell; strike the bell: the cork vibrates with the bell.

Exp. 3. Strike a tuning fork; touch the surface of some mercury with the end of the fork: the surface of the mercury exhibits little undulations or waves.

Exp. 4. Sprinkle some fine sand over a square piece of window glass; hold it firmly by means of a pair of pliers, and draw a violin bow down the edge: the sand is put in motion, and finally settles itself in those parts of the glass which have the least vibratory motion. By changing the point by which the plate is held, or by varying the parts to which the violin bow is applied, the sand may be made to assume different beautiful shapes.

34. All sonorous bodies are elastic; and the pitch of the tone which they emit depends upon the number of vibrations which they perform in a given time.

In all musical sounds the vibrations of the sonorous bodies are regular, that is to say, the rapidity of their vibrations remains unchanged. The

frequency of vibrations in strings increases with their *tension*, *shortness*, and *lightness*. By tightening the string of a violin the pitch of the note is raised, and the same effect is produced by shortening the string; in both cases the string is made to vibrate quicker. The pitch of the note also depends upon the thickness of the string; for example, the thinnest strings in the violin emit the highest sounds. In order to produce a musical sound, the number of vibrations performed by the string cannot be less than 32 per second; a string which vibrates twice as fast emits a note an octave higher, and a string which vibrates three times as fast emits a note two octaves higher, and so on. When the strings vibrate with the same frequency, the tones which they emit are in unison. The pleasing effect of harmonious sounds, such as thirds and fifths, is produced by the simplicity of the ratio of the vibrations performed in the same time; and, on the contrary, the disagreeable effect of discordant sounds arises from the want of this simplicity.

Where a continued sound is produced by impulses which do not, like those of an elastic body, follow in regular succession, the effect ceases to be a clear, uniform sound or tone, and is called a *noise*.

Transmission of Sound.

35. The experiment of the bell in the exhausted receiver (see p. 115) shows that a sonorous body may vibrate; yet if there is no medium to transmit the vibrations to the ear, no sound will be produced.

When a gun is discharged, the sudden expansion of the powder, compressing the air immediately around it, produces a condensation of the air a little farther away; this air, by its elasticity, expands, and in its turn produces a condensation of the air beyond it; and so on to a succession of pulsations or waves created by alternate condensations and expansions: in this way all sounds are propagated through the air. These successive pulsations or waves are *somewhat* like the successive rings formed in water when a stone is thrown into it.

36. Dense air is a better conductor of sound than rare air.

Hence it is that the sound of a pistol on the top of a high mountain is scarcely louder than the crack of a whip.

The distance at which a particular sound may be heard depends upon the state of the atmosphere with respect to density, moisture, &c. It is on account of the different states of the atmosphere that St. Paul's clock

is heard so much more distinctly at one time than at another. In calm, dry air the report of a musket may be heard at the distance of five miles, and the sound of cannon has been heard over water at the distance of 200 miles. In the open air the human voice may be heard at the distance of 230 yards; and Captain Parry informs us that at the polar regions, where the air is dense and dry, a conversation may be carried on between two persons a mile apart. The explosions of the volcano of St. Vincent were heard at Demarara, a distance of 340 miles. This is the greatest distance on record to which sound has been conveyed by the atmosphere.

Velocity of Sound.

37. When a gun is fired, we always see the flash before we hear the sound. Now, we see the flash almost instantaneously; but sound requires a sensible time to travel over any particular distance. In ordinary states of the air sound travels at the rate of 1120 feet per second.

From this we can readily calculate the distance at which a gun is fired when we know the interval of time which elapses between the flash and the sound.

Example. Required the distance at which a gun is fired when the report is heard three seconds after the flash is seen.

Here, distance travelled by sound in 1 second = 1120 feet;

Distance travelled in 3 seconds = 3 times 1120 = 3360 feet;
which gives the distance required.

In the same way we can find the distance of lightning from us, by observing the number of seconds which elapse between the flash and the sound of the thunder. As the human pulse very nearly beats once in every second, we may always readily find the interval between the flash and the sound by counting the beats of the pulse.

38. Solid as well as liquid bodies transmit sound even better than air.

Experiments.

Exp. 1. Strike two stones together under water: the sound will be as loud as if they had been struck in the air.

Exp. 2. Scratch the end of a log of timber with a pin: a person with his ear at the opposite end will distinctly hear the sound.

Exp. 3. Place the end of a long iron rod between the teeth, while the other end rests on the bottom of a hollow vessel: a whisper uttered within the mouth of the vessel will be distinctly heard, though it would be inaudible through the air.

Exp. 4. Suspend a poker by two strings, and press the ends one in each ear, while the poker is allowed to hang freely; strike the poker: a sound like the tolling of a large bell will be heard. Take the ends of the strings from the ear, and the sound will be comparatively feeble.

Reflection of Sound.

39. When sound strikes against any fixed surface, it is reflected from that surface, and the angle of reflection is equal to the angle of incidence. This law of reflection is the same as that which takes place with respect to any elastic bodies.

Thus, for example, when a marble is thrown obliquely on a hard pavement, it is reflected from the surface of the pavement at an angle equal to the incident angle — that is, equal to the angle at which it meets the surface of the pavement.

Echoes.

40. Reflected sounds produce echoes.

In order that an echo should be heard distinct from the sound which produces it, the reflecting surface must be at such a distance that the reflected sound would not be confounded with the original sound proceeding directly to the ear. Now, the human ear cannot appreciate more than ten separate sounds in a second; so that, in order that two successive sounds may be distinctly heard, the interval between them must be at least the tenth part of a second; and, since sound travels at the rate of 1120 feet per second, or 112 feet in the tenth part of a second, it follows that the reflected sound must travel over 112 feet more than the direct sound in order that the echo of a single sound or syllable may be distinctly heard from the sound itself.

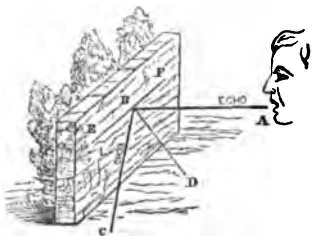


Fig. 52.

Let A be the place of a person giving utterance to a single sound; C the place of the person who hears the echo; E F any wall or obstacle which reflects the sound; A B the incident sound; B C the reflected sound; B D a line perpendicular to the plane of the wall: then the angle A B D is called the angle of incidence, and the angle D B C that of reflection. Now, the sound producing the echo travels through the distance A B added to B C, while the direct sound simply travels through the distance A C; and, there-

fore, if the former distance is 112 feet greater than the latter, the person at C would distinctly hear the echo of a single sound, as well as the sound itself. If the distance A B C exceeds A C by twice 112 feet, the echo of two distinct sounds may be heard, as in the case of the word *echo.* Some echoes repeat several syllables in succession. There are also some echoes which repeat the same word several times; this takes place when there are a series of reflecting surfaces placed at different distances from the speaker. When a hill or some other object obstructs the direct sound. the echo only may be heard.

Whispering Galleries.

41. Sound, as well as light, may be magnified by reflection; it is on this principle that whispering galleries are constructed.

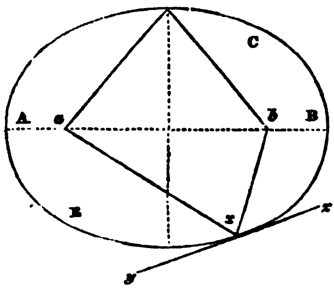


Fig. 53.

Let A C B E represent the wall of an elliptical building; then a whisper uttered at the focus *a* will be distinctly heard at the other focus *b*. Here the sound proceeding from *a* is reflected from every point in the wall to the point *b*; for example, the sound proceeding along the line *a x* is reflected along the line *x b*, where, from the property of the ellipse, the angle *a x y* of the incident sound is equal to the angle *z x b* of the reflected sound; and this takes place for every point in the ellipse. The form of the ellipse is peculiarly adapted for a whispering gallery, not only on account of the property just mentioned, but also on account of another property, viz.: the sum of the lines *a x* and *b x*, drawn from the foci *a* and *b* to any point in the ellipse, is always of the same length; from this it follows that the various reflected sounds reach the ear at the same instant. The whispering gallery of St. Paul's Cathedral, in London, depends upon a similar principle.

42. The *speaking trumpet* is much used at sea to render the human

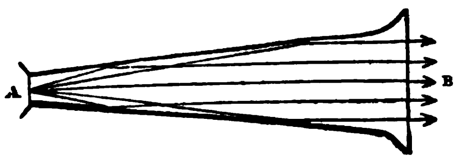


Fig. 54.

voice heard at a great distance. When a word is spoken at A, the sound is reflected from different points in the interior of the trumpet, so that the sound issues from the wide mouth B with an accumulated force. A strong man's voice, with a good instrument, may be heard at the distance of three miles.

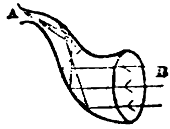


Fig. 55.

The hearing trumpet is very useful to persons dull of hearing, as it enables them to hear what is spoken to them. It depends upon the same principle as the speaking trumpet. The aperture A is placed within the ear of the deaf person, and the sound emitted at B is concentrated at A by a series of reflections.

43. *Further Examples.* — Almost any sound produced near a piano forte whose dampers are raised finds a responsive string.

A harp or guitar in a room with talking company is often mingling a note with their conversation.

Savages often discover the approach of footsteps by applying an ear to the ground.

Many a haunted house, so called, owes its reputation to some innocent cause which, operating without, is transmitted to the apartments within by the solid walls, and interpreted by the imagination into the language of ghosts. Even the beating of one's own heart, under a sense of fear, has been ascribed to a trip hammer in some distant machine shop.

The resonance of a room is irregular and indistinct when the room contains curtains, carpets, and other furniture, or a crowded assembly. Music halls have generally plain, bare walls.

WINDS.

44. Currents of air, or winds, are produced by the unequal distribution of heat over the earth. When the sun shines over any particular spot on the earth, the air immediately over the warm ground is rarefied by the heat, and consequently ascends, while the surrounding air, being cooler and heavier, rushes in to supply the place which the warm air has left vacant. In order to show the truth of this beautiful law of nature, the following experiment may be made: —

Exp. Make a wide pasteboard tube, and hold it in an inclined position, with its upper orifice near the flame of a candle or lamp; hold a lighted piece of paper near the lower orifice of the tube, and blow it out; the smoke from the paper is drawn up the tube, and rises with the ascending current of air proceeding from the candle.

The land and sea breezes, which chiefly occur in warm countries, afford a simple and an instructive illustration of the manner in which winds are generally produced. These winds blow from the sea to the land during the day, and the reverse of this takes place during the night. In the daytime the land becomes more heated than the water, and thus the air over the land, becoming rarefied, ascends; while the cool, dense air over the water rushes in to supply the place of the rarefied air. On the contrary, during the night the land loses its heat more rapidly than the water, until at length it becomes cooler than the water; in this case, therefore, a current of air sets in from the land to the water. These winds tend to equalize the temperature of islands and all places on the sea coast.

45. Winds are divided into three kinds: these are, the *constant* winds, which always blow in the same direction; the *monsoons*, or those which blow one half of the year in one direction, and the other half in the contrary direction; the *variable* winds, which do not appear to follow any regular law.

(1.) THE CONSTANT WINDS, which are also called TRADE WINDS, extend within 30 degrees on each side of the equator. The cause of these winds may be explained in the following manner: The equatorial portion of the earth being the hottest, the cool air from the temperate and polar regions rushes towards the equator to supply the place of the heated air, which is there constantly ascending; and if the earth were not to turn on its axis, this would occasion two winds, one blowing directly from the north pole towards the equator in the northern hemisphere, and the other blowing from the south pole to the equator in the southern hemisphere; but as the earth revolves from west to east, the air towards the poles has a less rotatory motion than the solid parts of the earth at the equator; it consequently follows, that when this air arrives at the equator it does not move with the same speed as the earth, and thus a wind blowing from the east (contrary to the earth's motion) is produced at the equator.

Now, the air within the *northern tropic*, before it reaches the equator, has a twofold motion — that is to say, it has its original motion from north to south, and, owing to the earth's rotation, it has relatively a motion from east to west; but as these motions take place at the same time, it causes the wind to blow from the north-east, which is the direction of the trade in the northern tropic. Reasoning in the same manner, it follows that the trade wind in the *southern tropic* must blow from the south-east.

These winds tend to equalize the temperature of the globe, and to maintain the purity of the atmosphere; for while the cool air of the

polar and temperate regions is constantly descending towards the torrid zone, the warm air of this zone is constantly ascending and moving towards the polar and temperate region of the earth; thus while the cool air of the frigid and temperate zones moderates the excessive heat of the torrid zone, at the same time the warm air of the latter elevates the temperature of the former.

If the earth within the tropics were covered with water, the trade winds would regularly blow in the manner just described; but owing to the unequal distribution of land and water, these winds are subject to certain remarkable deviations. As might have been expected, the trade winds blow with the greatest regularity over the expanse of the Pacific Ocean.

(2.) MONSOONS. — When a trade wind is turned back or diverted by overheated districts from its regular course at stated seasons of the year, it is regarded as a *monsoon*. Thus the African monsoons of the Atlantic, the monsoons of the Gulf of Mexico, and the Central American monsoons of the Pacific are, for the most part, formed of the north-east trade winds, which are turned back to restore the equilibrium which the overheated plains of Africa, Utah, Texas, and New Mexico have disturbed.

When the monsoons prevail for five months at a time, (for it takes about a month for them to change and become settled,) then both they and the trade winds, of which they are formed, are called monsoons. The south-west and north-east monsoons of the Indian Ocean afford an example of this kind. The south-west monsoons of the Indian Ocean blow from May to September inclusive. They are caused by the intense heat which the rays of a cloudless sun produce during the summer time upon the Desert of Cobi and the burning plains of Central Asia. When the sun is north of the equator, the force of his rays, beating down upon these wide and thirsty plains, causes the air to expand and ascend. There is, consequently, a rush of air, especially from towards the equator, to restore the equilibrium; and in this case the force which tends to draw the north-east trade winds back becomes greater than the force which is acting to drive them forward.

When it is summer time in Africa south of the equator, the winds are blowing from the north-east, in obedience to the trade wind force, which prevails from November to March inclusive; hence we have the north-east monsoons. The monsoon season may always be known by referring to the cause which produces these winds. Thus, by recollecting where the dry and overheated plains are, we know at once that these winds are rushing with greatest force towards these plains at the time of their hottest season of the year

These winds are of considerable importance to navigators who make voyages to the East Indies.

(3.) THE VARIABLE WINDS blow at all places at a distance from the equator. The variableness depends upon a variety of causes; for whatever tends to disturb the equilibrium of the atmosphere will occasion a change in the direction of the wind.

The cold air of the polar regions is constantly flowing towards the warmer regions, partly as an upper current, according to the general law of atmospheric circulation, and partly as a surface wind: hence in the northern hemisphere we have a prevalence of north-east winds. These winds, finding an open path in North America, from one end of the continent to the other, sweep from the borders of the Arctic Ocean as far as the Gulf of Mexico. They strike obliquely against the Rocky Mountains, run along their slopes, and, being reflected by this high chain, descend as a north-west wind into the valley of the Mississippi, accompanied by cold and storms. Proceeding towards the Atlantic coast, they meet the south-west or the equatorial winds.

This conflict between the polar and equatorial winds, so opposite in character and direction, gives to our climate one of its most remarkable features, — that of changeableness, — that great variety of temperature, of drought and of humidity, of fair weather and foul, which mark the seasons with uncertainty, and the labors of the husbandman with doubtful results.

Sirocco and Simoom.

There are certain winds which have received peculiar names, such as the *Sirocco* and the *Simoom*. These winds are injurious to life, on account of the burning sands, or on account of the pestilential swamps, over which they blow.

The *Sirocco* blows from Africa over the south of Europe; it is especially felt in the south of Italy and Spain. During the continuance of this hot wind, the vegetable creation loses its freshness and beauty, and the animals of the field, as well as man, appear to languish and droop with excessive exhaustion.

The *Simoom*, which blows over the burning deserts of Africa and Asia, is of all other winds the most destructive to life. The breathing of this wind sometimes occasions instantaneous death; and to save their lives, travellers usually throw themselves down with their faces on the ground, until the desolating wind has passed over them.

46. Winds receive names according to the rate at which they blow. When a wind blows at the rate of 5 miles an hour, it is called *a gentle breeze;* at 10 miles an hour, *a brisk gale;* at 40 miles an hour, *a high wind* or *storm;* and at 80 miles an hour, *a hurricane.* The force of the wind increases with the square of the velocity: thus a hurricane, having

8 times the velocity of a brisk gale, would strike trees and houses with 64 times the force that a brisk gale would do.

BALLOONS.

47. Balloons rise in the atmosphere in the same manner as smoke ascends, or as a cork rises in water. A soap bubble is a little balloon inflated with the warm air from the lungs; and it ascends because it is specifically lighter than the surrounding air. A balloon is sometimes made of thin paper; the air which it contains is rarefied by means of the flame of a piece of sponge dipped in spirits of wine and placed beneath an opening made in the under part of the balloon. This kind of balloon was invented by Montgolfier.

From its extreme lightness, hydrogen is better fitted than any other substance to inflate balloons; though coal gas, from its greater cheapness, is generally used. Very large gas balloons, of a pear-like shape, are made of oiled silk, and inflated with common street gas, which is considerably lighter than atmospheric air. The balloon, being filled with this light gas, is rendered specifically lighter than the air; it therefore ascends until it arrives at an elevation where the surrounding air and the balloon have the same specific gravity. The car which bears the aeronaut is supported by network which goes over the body of the balloon. When the aeronaut wishes to descend, he pulls a cord which opens a valve at the top of the balloon, and thus allows a portion of the light gas to escape, and thereby renders the balloon specifically heavier than the air.

The buoyancy, or ascending force, of a balloon may be easily calculated. Suppose the balloon to contain 32,000 cubic feet of gas, the weight of each cubic foot of air to be $1\frac{1}{10}$ ounces, and the weight of each cubic foot of gas to be 1 ounce; then each cubic foot of the balloon will have a buoyancy of $\frac{1}{10}$ of an ounce, and the whole balloon will have a buoyancy of 3200 ounces, or 200 lbs. If the weight of the car and the material of the balloon be 60 lbs., then the balloon will ascend when the weight of the aeronaut does not exceed 140 lbs.

48. *Additional Facts.* — The pressure of the atmosphere at the surface of the earth keeps a certain quantity of air in combination with water, so as to form part of the liquid mass. The air reappears at once on taking off the pressure. This admixture of air in water is necessary to the life of fishes.

A balloon which is only half full at the surface of the earth becomes quite full when it has risen $3\frac{1}{2}$ miles, because at that height air from below doubles its volume, on account of the diminished pressure.

The downy seeds of plants seen floating about upon the winds of autumn are not lighter than air, but have so much bulk and surface in

proportion to their weight, that the friction upon them of the moving air is greater than their weight, and carries them along.

Smoke consists of the dust and visible particles which are separated from the fuel without being burned, and light enough to be carried aloft by the rising current of heated air; but all that is visible of smoke is really heavier than air, and soon falls again.

When a low house adjoins a lofty one, the wind blowing towards the latter is obstructed; and if the top of a low chimney be there, the compressed air enters it and pours downwards. Again, whenever from the nature of buildings eddies of wind occur, or unequal pressures, as at street corners, &c., the chimneys around do not act regularly.

Exercises on Pneumatics.

1. If 100 cubic inches of atmospheric air weigh 30 grains, what will be the weight of 1 cubic foot? (See Art. 5.) *Ans.* 1.08 oz.

2. When the elevation of the mercury in the barometer is 28 inches, what will be the height of a column of water supported by the atmospheric pressure? (See Art. 8.)

Column of mercury supported by the atmosphere = 28 in.;

" water " " " $= 13\frac{1}{2} \times 28$ in.;

$= 31\frac{1}{2}$ feet.

3. Required the same as in the last example, when the elevation of the mercury is 24 inches? *Ans.* 27 feet.

4. Allowing that a cubic inch of mercury weighs $\frac{1}{2}$ lb., what would be the pressure of the atmosphere at the top of a mountain, where the mercury in the barometer stands at the height of 20 inches?

Ans. 10 lbs. per sq. in.

5. A given portion of air has a pressure of 15 lbs. per square inch when its volume is 5 cubic feet: what will be its elasticity when it is compressed into the space of 3 cubic feet? (See Art. 16.)

Pressure when its vol. is 5 c. ft. = 15 lbs.;

" " vol. is 1 c. ft. $= 5 \times 15$ lbs.;

" " vol. is 3 c. ft. $= \frac{5 \times 15}{3} = 25$ lbs.

6. Required the same as in the last example, when the original pressure is 20 lbs. with a volume of 2 cubic feet, and the new volume is 5 cubic feet? *Ans.* 8 lbs.

7. If the column of mercury in the gauge of the air pump (see Art. 19) stands at 27 inches, when the mercury in the barometer is 30 inches, what is the elasticity of the air in the receiver, as compared with the external air? *Ans.* $\frac{1}{10}$.

8. If the section of the Magdebourg hemispheres (see Exp. 3, Art. 20) contains 6 square inches, and it requires a weight of 87 lbs. to separate them, what is the pressure of the external air upon each square inch?

Ans. 14½ lbs.

9. To what height may water be raised by the common pump, at a place where the barometer stands at 24 inches?

Ans. 27 feet. (See Art. 21.)

10. In the hydrostatic press, (see Art. 26,) if the large piston P contains 18 square inches, the small one 1½ square inches, and if the advantage gained by the lever G H is 6, what will be the pressure exerted upon the press board, when a pressure of 60 lbs. is applied to the handle?

Here the whole pressure on the small piston is 6 times 60 lbs., or 360 lbs.; that is,

Pressure on 1½ sq. in. = 360 lbs.;
" 18 sq. in. = 12 times 360 lbs. = 4320 lbs.;

which gives the upward pressure on the large piston.

11. Required the same as in the last example, when the large piston contains 20 square inches, the small one 2 square inches, the pressure on the handle being 40 lbs., and the advantage gained by the lever 8?

Ans. 3200 lbs.

12. Required the distance of lightning when the flash is seen 9 seconds before the thunder is heard? (See Art. 37.)

Ans. 1 mile 600 yards.

13. At what distance must a gun be fired so that the interval between the flash and the sound may be 3½ seconds? *Ans.* 3020 feet.

LIGHT AND HEAT.

LIGHT.

1. LIGHT renders the objects in the external world visible to us: the sense of sight is the eye; the rays of light, proceeding from surrounding objects, enter the eye, that wonderful optical instrument, and by acting upon the optic nerve, produce the sensation of vision.

2. Light emanates from all *luminous bodies* — such as the sun, the stars, and substances in a state of combustion.

The sun is the great source of light as well as of heat; but there are many other sources of light, such as — (1.) *Chemical light*, or that which is derived by chemical action; (2.) *Electric light*, or that light which is evolved by the electric spark; (3.) *Light of friction*, that which is obtained by striking two dissimilar hard bodies together; (4.) *Phosphorescent light*, or that light which is emitted by certain bodies at the ordinary temperature of the air.

3. *Non-luminous* bodies become visible to us only by reflecting the light which falls upon them from some luminous body.

The fixed stars, as well as the sun, shine by their own light; but the moon and the planets, with their satellites, shine only by reflected light.

4. Bodies are divided into *transparent* and *opaque*. Transparent bodies, such as glass, allow the rays of light to pass freely through them; in other words, we can see objects through them. Opaque bodies, such as a sheet of tin, do not allow the rays of light to pass through them.

5. Light travels at an inconceivably rapid rate.

It takes about eight minutes in travelling from the sun to us, that is, it moves at the rate of about 192,000 miles per second. As regards all phenomena upon earth, they may be considered as happening at the *very instant* when the eye perceives them; the difference of time being too small to be appreciated.

Light proceeds from visible objects in straight lines.

Thus we can only see a body, when looking through a straight tube, by directing the tube towards the body.

6. The intensity of light varies with its distance from us; that is to say, like all other principles which emanate from a centre, the intensity of light decreases as the squares of the distances increase.

Thus, at the distance of two yards, the intensity of light will be one fourth of what it is at one yard; at three yards, the intensity will be one ninth of what it is at one yard; and so on: the reason of this is rendered manifest by Fig. 1.

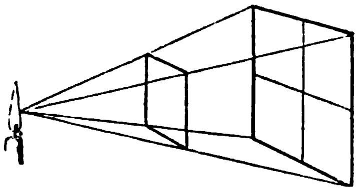


Fig. 1.

7. There are two remarkable laws of light, viz., *reflection* and *refraction*.

Every boy is familiar with the reflection of the sunlight from a bit of looking glass.

When we look upon the surface of a stream, we see the objects on its opposite bank reflected from its surface. In this case, the reflected images of the objects appear turned upside down.

We see our faces reflected from the surface of the looking glass. In this case, the side of our face to the left appears on the right of the reflected image.

We plunge a stick into water; the stick appears bent: this is owing to *refraction*.

We look through a tumbler of water upon an object placed on the opposite side; the object appears very much enlarged and somewhat distorted: this is owing to refraction: the rays of light proceeding from the object are changed from their right-lined course in passing through the transparent medium. This change of direction is called the effect of refraction.

8. The great Newton considered that light is an emanation from

luminous bodies, and consists of very minute particles which are too fine or subtile to exhibit the ordinary properties of matter, and which travel in straight lines with inconceivable velocity, and produce the sensation

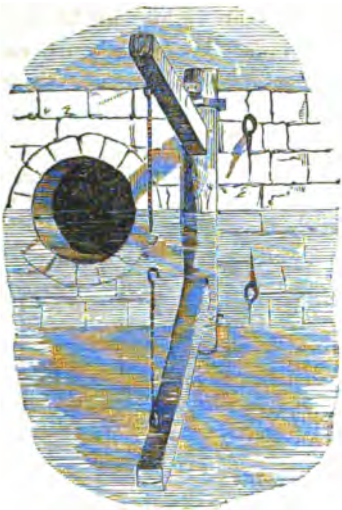


Fig. 2.

of light by passing into the eye, striking against the expanded nerve of vision called the *retina*. This has been called the *corpuscular theory of light*. There is another theory of light, pretty generally now adopted by philosophers, which is known as the *undulatory theory of light:* according to this theory light is supposed to be propagated by the undulations of a subtile ethereal medium which pervades all space. Now, as either of these theories serves the purpose of explaining and classifying the facts which we shall have occasion to notice, we shall not limit ourselves by decidedly adopting either the one theory or the other.

EXPERIMENTS ELUCIDATING THE LEADING PRINCIPLES OF OPTICS.

9. REFLECTION.

Exp. 1. Lay a small looking glass upon the floor, with its face uppermost; place a burning candle on the floor, at some distance from the looking glass, so that the light from the candle may fall obliquely upon the surface of the glass: place yourself on the side opposite to the candle, shifting your position until you catch a sight of the image of the candle reflected from the glass.

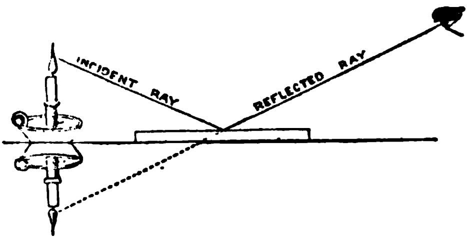


Fig. 3.

(1.) The *reflected ray* makes the same angle with the glass as the *incident ray.*

(2.) The image of the candle appears as much *below* the surface of the glass as the candle itself stands *above* the glass.

Bring the candle about a foot nearer to the reflector: then you will have to bring your eye the same distance nearer to it; thereby showing that the reflected ray always makes the same angle with the surface of the reflector that the incident ray does.

The angle of reflection is always equal to the angle of incidence.

Thus, let E F be the reflecting surface, A B the incident ray, B C the reflected ray, and B P a perpendicular to the surface E F; then the angle A B P which the incident ray makes with this perpendicular is called the angle of incidence, and the angle C B P which the reflected ray makes with this perpendicular the

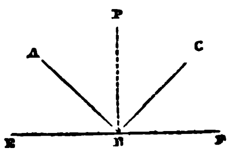


Fig. 4.

angle of reflection; and these two angles are always equal to each other.

It is quite true, at the same time, that the angle A B E, which the incident ray makes with the surface of the reflector, is always equal to the angle F B C which the reflected ray makes with the surface of the reflector.

In Fig. 5, A B is the incident ray proceeding from the top of the tree, and B C the reflected ray; E F is the incident ray proceeding from one of the lower branches, and F C the reflected ray. Now, because of the

Fig. 5.

equality of the angles of incidence and reflection, the image D of the top of the tree appears as much below the surface of the water as the top of the tree A is really above it.

Exp. 2. To obtain three or more reflected images of an object. — Place a small mirror perpendicular to a larger one: put any object between them; bring your eyes in front of the smaller mirror; you will distinctly see three reflected images of the object — that is, one image from the reflection of the large mirror, another from the reflection of the small mirror, and a third from the double reflection of the two mirrors.

Place yourself before two large, parallel looking glasses, fixed to the opposite walls of a room, and you will see a countless series of images reflected from the glass. This effect is produced by a series of successive reflections.

Exp. 3. To get a sight of the back of your head. — Place yourself with your back towards a large looking-glass; hold a small looking glass with its face towards you, but a little to one side, and with its surface somewhat inclined to the plane of the large mirror; after a little adjustment you will get a distinct view of the back portion of your head. It is scarcely

necessary to say that this is due to two reflections: the back part of your head is reflected from the large mirror to the small one, and then this last image is reflected from the surface of the small mirror to the eye.

Exp. 4. *A person may see his whole figure reflected from the surface of a comparatively small mirror.* — Place yourself a few feet in front of a mirror A B; move backwards until you get a sight of your whole figure: the rays of light C A proceeding from your head fall perpendicularly upon the mirror, and are therefore reflected back in the same line; the rays B D proceeding from your feet fall obliquely upon the mirror, and are therefore reflected according to the law of reflection before explained, in the direction B C; so the image of the image of the feet is seen at F in the direction of the line C B produced. The image, as before stated, will appear to be standing as much behind the glass as the actual figure is standing before it.

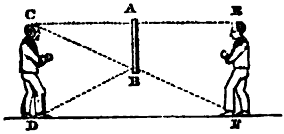


Fig. 6.

Exp. 5. *The magic perspective,* as it is called, is produced by an arrangement of reflectors which enables a person to see an object notwithstanding the interposition of an opaque screen. *l*, *h*, *g*, and *k* are looking glasses inclined at angles of 45° to the horizon; P is the object, P *l* the incident rays, and *l h g k* A the course of the reflected rays; and the eye at A perceives the image of the object in the last mirror in the direction A *k*.

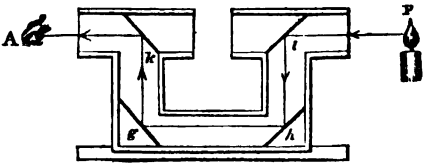


Fig. 7.

Exp. 6. *The kaleidoscope* consists of a long tube, blackened inside, having three pieces of looking glass inserted in it lengthwise; one end of the tube is closed by a piece of window glass, and on it is fitted a continuation of the tube, the end of this tube being closed with a piece of ground window glass; the space between these two glasses, which does not exceed a quarter of an inch, is filled with pieces of colored glass; the other extremity is covered with a cap having a small hole through its centre, to which the eye must be applied. Hold the tube with the ground glass to the light; look through the hole at the pieces of colored glass, and the image of a regular hexagonal star will be seen. The effect is due to the successive reflections which take place from the surfaces of

the three mirrors; the rays proceeding from each bit of glass undergo five reflections, which, with the object itself, presents six distinct images to the eye.

Exp. 7. *A concave mirror.* — Look into the concave face of a watch glass, taking care to have a dark ground behind it; after adjusting for the focus, you will see a small inverted image of your face reflected from the concave surface of the glass.

Hold a small object, such as the head of a pin, very near to the surface of the reflector: an enlarged image of the object will be seen behind the glass.

A convex mirror. — Look at the convex face of the watch glass, and similar effects will be observed.

10. REFRACTION.

Exp. 1. *To form the image of a candle by the transmission of its light through a hole.* — Pierce a thick sheet of writing paper with a stout

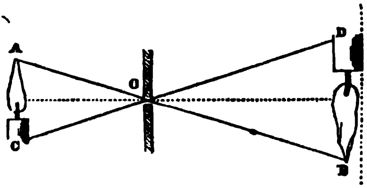


Fig. 8.

darning needle; hold the paper between a lighted candle and the wall of the room: an inverted image of the candle will be thrown upon the wall; move the paper forwards or backwards, until you have attained that position which gives the most distinct image: you have then got the focus.

This effect is simply due to the principle that *light is propagated in straight lines.* The rays of light proceeding from the object cross one another in passing through the orifice O; the rays from the top A of the candle, pursuing the straight line A O B, fall upon the wall at B; and, in like manner, the rays from the bottom C of the candle fall upon the wall at D, thereby producing an inverted image of the candle upon the wall.

Bring the candle nearer to the wall, and at the same time shift the position of the orifice so as to adjust the focus, and you obtain an image of smaller size, but of more intensity.

Exp. 2. Place an empty vessel so as to make the shadow of its edge

to fall exactly at the lower angle *b* — that is, so that the ray of light proceeding from the candle shall be in the direction *s d b;* now fill the vessel with water, and the light from the refraction of the liquid will be extended over the bottom of the vessel, as shown in Fig. 9.

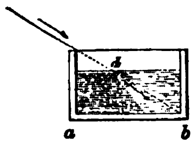


Fig. 9.

Exp. 3. Place a coin C at the bottom of an empty tumbler; bring your eye E in a line E K C with the edge of the glass and the outer edge of the coin; without moving your eye, pour water into the glass: the whole of the coin will now be visible — that is, it will be seen in the direction E D B. The ray C D upon passing out of the water becomes bent in the direction D E, so that the edge C is now seen in the direction E D B.

When a ray of light is thus bent from its straight-lined course, it is said to undergo *refraction.*

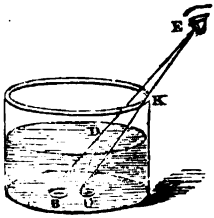


Fig. 10.

Light always undergoes refraction when it passes obliquely from one medium to another. But when the light passes perpendicularly from the surface of the one medium to that of the other, it is not altered in its straight-lined course.

Exp. 4. Fill a tumbler with water; place the leaf of a book close to one side of the glass; look through the water at the print; you will see it much enlarged. Here the round portion of the glass acts as a *convex lens,* which, on the principle of refraction, causes the print to appear larger than it really is.

A cylindrical bottle filled with water, used in this manner, makes a good *microscope.*

A good *reading glass* may be formed by crossing two bottles filled with clear water, as shown in Fig. 11, and looking through the crossed portion.

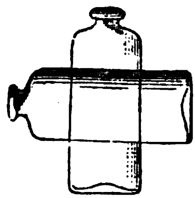


Fig. 11.

Exp. 5. Take one of the convex lenses of an aged person's spectacles, and hold it between a candle and the wall of the room; an inverted image of the candle will be thrown upon the wall; move the lens forwards or backwards until you have attained that position which gives the most distinct image; you have then got the focus of the lens.

Here the central rays *c* F C pass perpendicularly through the lens,

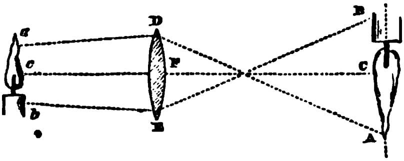


Fig. 12.

and undergo no refraction; the extreme rays *a* D, falling obliquely upon the lens, are bent in passing through it, and are thus bent or refracted into the course D A; in like manner, *b* E is refracted into the direction E B; and hence the image of the candle appears inverted.

Exp. 6. Look through the spectacle eye upon some print; move the lens up or down until you have got the focus; the print will appear considerably enlarged.

Perform the same experiment with the lens of the spectacles used by a short-sighted person; the print will appear smaller than it really is. In this case, the lens is hollow or concave.

Exp. 7. Take any piece of cut glass, such as the stopper of a decanter bottle, and hold it between your eye and the light; keep turning it round, and you will see all the colors of the rainbow. A triangular piece of cut glass, called a glass prism, will answer the purpose best. Here the rays of light are decomposed, by refraction, into their different colored pencils of light.

Exp. 8. *To produce an artificial rainbow.* — When the sun is shining near the horizon, get a person to project water from a wet broom; place yourself between the sun and the scattered water, having your face towards the shower of drops, and you will observe all the colored tints of the rainbow. Here the little drops of water obviously decompose the light.

Exp. 9. (1.) Observe that while you blow a soap bubble, the varied tints of the rainbow may be seen reflected from the thin film of fluid forming the bubble. The varying thickness of the film produces these changes of color.

(2.) Observe also the colors exhibited by a drop of oil as it spreads itself over the surface of water.

(3.) Take a watch glass and a piece of common window glass; press the two steadily together, and luminous rings will be seen about their point of contact.

These phenomena depend upon what has been called the *interference of light.*

Exp. 10. (1.) Hold a fine needle close to one eye, the other being shut; and look fixedly at it, against any light object as a background; you will see several needles.

(2.) Make a straight cut in a piece of card board; look through the narrow opening at the candle; on each side of the real candle you will see other candles marked with the colors of the rainbow.

(3.) If the light of the sun be admitted into a dark room, by a very narrow chink, several luminous chinks, separated by dark bands, will be visible on the opposite wall.

(4.) Suspend a black ball in the sunlight; the round shadow of the ball will contain bands of light.

These phenomena depend upon what has been called *the diffraction of light.*

REFLECTION OF LIGHT FROM CONCAVE AND CONVEX MIRRORS.

11. Mirrors are divided, according to the form of their surfaces, into *plane, convex,* and *concave.* The common looking glass is a plane mirror.

The law of the reflection of light, which has been explained, holds equally true with respect to convex and concave reflectors.

Let *a c b* represent a plane mirror, *f c g* a convex mirror, and *d c e* a concave mirror, all touching each other in the common point *c*; *c l* a

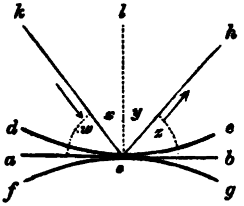


Fig. 13.

perpendicular to the plane *a b*; *k c* the direction of the incident ray, and *c h* the direction of the reflected ray; then *k c l* will be the angle of incidence, and *l c h* the angle of reflection, to any of these mirrors, and these angles will always be equal to each other — that is, angle *x* will be

equal to angle *y*, and, as a necessary consequence, angle *w* will be equal to angle *z*. It will be observed that *a b* forms a tangent to the curved mirrors at the point of contact *c*, and that *c l* is perpendicular to the curves at the point *c*, being perpendicular to the tangent line *a b*.

12. CONCAVE MIRRORS.

The general effect of concave mirrors is to produce an image *larger* than the object itself.

Let *s v s* (Fig. 14) represent a concave mirror; *c* its centre, that is, *c* is the centre of the circle *s v s*; *r* a luminous point, or the flame of a small candle; then incident rays *r s*, *r s*, falling upon the surface of the mirror, will be reflected to the same point *t*, in the directions *s t*, *s t*, making the angle of incidence *r s c* equal to the angle of reflection *c s t*. At the point *t*, called the focus of the mirror, a small image of the luminous object will be formed, which may be received upon a piece of thin white paper. The line *c v* produced is called the axis of the reflector.

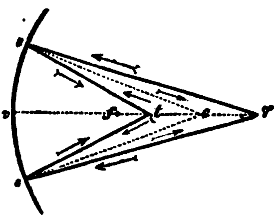


Fig. 14.

The points *r* and *t* are convertible; that is to say, if the flame of the candle be placed at *t*, then *r* becomes the focus, and an enlarged image of the candle will be formed at this point.

When the rays of light *r s*, *r′ s′*, &c., (Fig. 15,) fall upon the concave mirror *s v s′*, parallel to the axis *c v*, they are reflected into a point *f*, exactly midway between the reflector and its centre *c*. The point *f* is called the *principal focus*, and its distance *f v* from the speculum or reflector is called the *principal focal distance*.

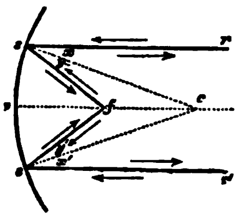


Fig. 15.

In Fig. 14, *f* is the *principal focus*, making *f v* = *f c*; *t* is *a focus* to the rays proceeding from a luminous point at *r*; in this case the incident rays are not parallel to the axis; hence, by way of distinction, the focus of parallel rays is called the *principal focus*.

When the rays of light come from a point *r* beyond the centre *c*, as in Fig. 14, the reflected rays will all converge to the focus *t*

between the principal focus *f* and the centre *c* of the speculum; on the contrary, if the rays of light come from a point *r* (see Fig. 16) between the mirror and the principal focus, the reflected rays *s q*, *s q'*, &c., will all diverge from the axis V *c*. If the luminous body be placed in the principal focus *f*, (see Fig. 15,) then the reflected rays *s r*, *s r'*, &c., will all be parallel to one another.

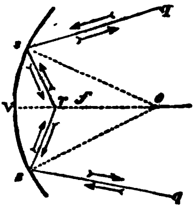


Fig. 16.

The image of the object is inverted. Let D E be the concave mirror, (see Fig. 17;) C its centre; A B a distant object placed before it; and *a b* its inverted image, reflected from the mirror. Here the incident rays A D, proceeding from the point of the arrow,

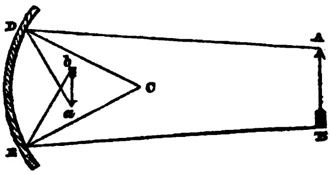


Fig. 17.

are reflected in the direction D *a*, making the angle of reflection C D *a* equal to the angle of incidence A D C; and the incident rays B E, proceeding from the foot of the arrow, are reflected in thé direction E *b*, making the angle of reflection C E *b* equal to the angle of incidence B E C; and so on to other points; thereby producing the little inverted image *a b* of the arrow in the focus of the reflector.

If a small object be placed at the focus *a b*, then an enlarged image will be formed at A B.

Exp. 1. Place a candle at a distance, opposite to a concave mirror, (see Fig. 17;) hold a thin piece of white paper near the surface of the mirror; a small, bright, inverted image of the candle will be thrown upon the paper; move the paper backwards or forwards until you have got the exact focus.*

Exp. 2. Reverse the last experiment, that is to say, place the candle in the focus, and then an enlarged image will be thrown upon the paper placed at A B.

Exp. 3. Hold the concave mirror facing the sun; hold a piece of paper in the focus, and an intensely bright image will be formed, which

* A common tin reflector answers very well for making these experiments.

will almost instantly ignite the paper. This forms a burning mirror. In this case the luminous image lies in the principal focus of the reflector.

Exp. 4. Place the candle in the principal focus of the reflector; the rays of light will all be reflected parallel to the axis, and will illuminate the wall of the room upon which they are thrown. Bring the candle still nearer to the reflector, and the reflected rays will all diverge from the axis, and will illuminate a greater extent of surface.

Exp. 5. Place the object N S between the mirror and principal focus

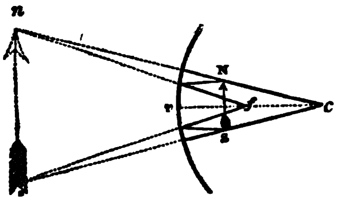


Fig. 18.

f, as shown in Fig. 18; an enlarged image of the object will be seen, in its erect position, behind the mirror.

Exp. 6. *The magic mirror.*—Place a small object *s n*, concealed from the view of the observer, between the centre *c* and the principal focus *f*; receive the enlarged image N S through an opening cut in a board; look in the direction of this opening, and you will see the image suspended, as it were, in the air.

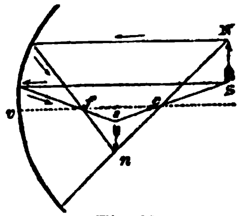


Fig. 19.

This effect is easily explained on the principles which have been already expounded.

13. CONVEX MIRRORS.

The *principal focus* of a convex mirror lies as far behind the reflecting surface as in concave mirrors it lies before it. The focus in this case is called the *virtual focus*, because it is only an imaginary point, towards which the rays of reflection appear to be directed.

Let N S be an object placed before a convex mirror, (see Fig. 20;) *c* the geometrical centre of the mirror; *f* the principal focus; N A an

incidental ray; *c* A D a straight line drawn from the centre *c*; A B the course of the reflected ray, making the angle of reflection D A B equal to the angle of incidence N A D; then a small direct image *n s* will be formed in the focus.

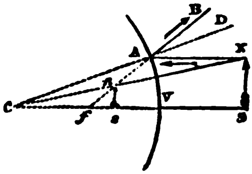


Fig. 20.

The general effect of convex mirrors is to produce an image *smaller* than the object itself.

The phenomena of reflected images is more fully exhibited in Figs. 21 and 22.

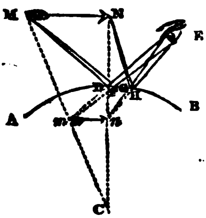


Fig. 21.

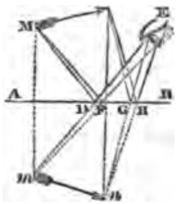


Fig. 22.

The incident rays M D, M F, are seen in the directions D *m*, F *m*; and N G, N H, are seen in the directions G *n*, H *n*; where the distance A *m* and F *n* behind the mirrors have a certain correspondence with the respective distances of the points M and N in front of the mirrors.

THE REFRACTION OF LIGHT.

14. The following remarkable law obtains in relation to the refraction of light: When a ray of light passes from one transparent medium to another, *the sine of the angle of incidence has always a constant ratio to the sine of the angle of refraction.*

Suppose *m n* be the surface of water, (see Fig. 23;) *a b* the *incident* ray, making with the perpendicular *h b d* the *angle of incidence x* or *a b d*; *b c* the refracted ray bent from the right line *a b f*, and forming the *angle of refraction y*, or *c b h*. With *b* as a centre, describe the circle *a d c*; and on *h d* let fall the perpendiculars *a g* and *c h*; then *a g* is

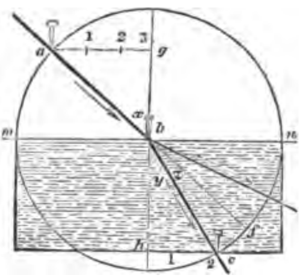


Fig. 23.

called the *sine of the angle of incidence*, and *c h* is called the *sine of the angle of refraction*, and those two lines have always a constant ratio to each other, viz., as 4 to 3, or as 1.336 to 1, whatever (within certain restrictions) may be the angle at which the ray *a b* meets the surface of the fluid. The number 1.336 is called the *index of refraction* for water. When the medium is flint glass, the sine of the angle of incidence *a g* is to the sine of the angle of refraction *c h* as 3 to 2, or as 1.5 is to 1 nearly. The number 1.5 is called the index of refraction for flint glass. Glass, therefore, has a higher refractive power than water. Generally speaking, *the denser the medium the higher is its refractive powers.*

When a ray of light passes from a rare to a dense medium, as, for example, from air to water, the refracted ray is bent *towards* the perpendicular; so, conversely, when the ray passes from a dense to a rare medium, the refracted ray is bent *from* the perpendicular.

Newton accounted for the refraction of light on the supposition that media of different compositions exert an attractive power on the rays of light when they approach their respective boundaries: thus the fluid *m n* (see Fig. 23) is supposed to exert an attractive influence upon the incident ray *a b*, when it approaches the surface *m n*, and thereby bends the course of the ray downwards.

Passage of a Ray through a Plate of Glass.

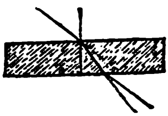


Fig. 24

15. The ray will be bent downwards upon entering the plate, but it will be bent as much in the contrary direction upon passing out of the plate, as shown in Fig. 24, so that the course of the ray after refraction will be parallel to the direction which it had before refraction.

Passage of a refracted Ray through a Prism.

16. Let C (Fig. 25) be a prism of glass; *a r* the incident ray falling perpendicularly on one face of the prism; then the ray will undergo no

13*

refraction on entering the prism, for it will pursue the straight course *a r c*; but upon leaving the oblique face of the prism, the ray will be bent towards the surface of the glass, or, what is the same thing, it will be bent from the perpendicular *c m*, and will move on in the direction *c* E. If the incident rays had been inclined to the plane of the first face, they would have undergone two different refractions.

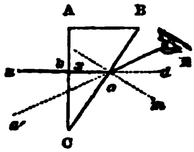


Fig. 25.

The Multiplying Glass.

17. A D C B represents a section of a piece of cut glass having three faces, A D, D C, and C B, inclined to one another, as shown in Fig. 26; *d* an object placed in front of the face A B; then an eye at *a* will see three distinct images of the object. The rays *d b* undergo refraction in passing from the face A D, and *d b* in passing from B C, and so on to the other faces. The number of images seen always corresponds to the number of inclined faces in the multiplying glass.

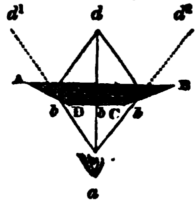


Fig. 26.

Refraction in Lenses or Glasses with curved Faces.

18. There are six different forms of simple lenses.

No. I., Fig. 27, represents a *double convex* lens; No. II. a *plano-convex* lens; No. III. a *meniscus* lens, like a watch glass; No. IV. a *double concave* lens; No. V. a *plano-concave* lens; and No. VI. a *concavo-convex* lens.

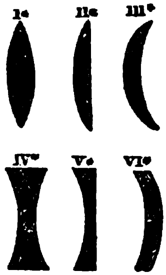


Fig. 27.

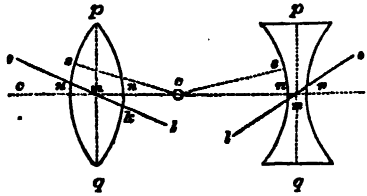


Fig. 28.

Definitions relative to lenses. — The line *p q* (see Fig. 28) is called the *diameter*; *c* the *geometric centre*; *c n* the *axis*; *m* the *optical centre*; *l m o* a principal when it passes through the optical centre.

Radii, *c n*, *c s*, &c., being at right angles to the curved surface, constitute the perpendiculars from which the angles of incidence and refraction are estimated.

FOCAL DISTANCES OF LENSES.

19. *Double convex lenses.* — When the incident rays are *parallel*, the distance of the focus *f* is equal to the radius of the spherical surface, as shown in Fig. 29. Here *f* is called the principal focus.

When the incident rays are *divergent*, as in Fig. 30, the focus *r* lies beyond the principal focus *f*.

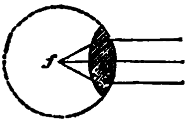


Fig. 29.

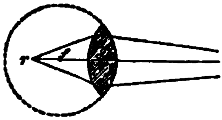


Fig. 30.

When the incident rays are *convergent*, as in Fig. 31, the focus *r* lies within the principal focus.

20. *Plano-convex lenses.* — When the incident rays are parallel, the distance of the focus *r* is equal to the diameter of the spherical surface, as shown in Fig. 32.

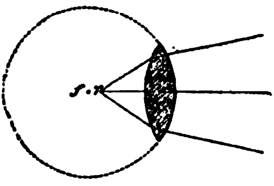


Fig. 31.

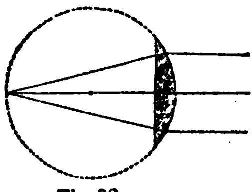


Fig. 32.

21. In the *double convex lens* L L, Fig. 33, O and O′ are the centres of the surfaces of the lens, and also the principal foci; R the radiating

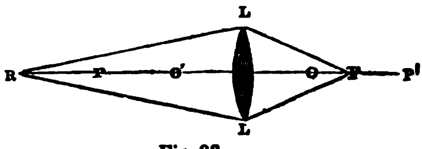


Fig. 33.

point; F the focus; and when R approaches to P, the focus F recedes to P′; and when R comes to O′, the focus is infinitely distant.

22. *Double concave lenses.* — Divergent incident rays diverge still more after refraction, and seem to proceed from a point nearer to the lens than that from which they actually proceed, as shown in Fig. 34, where the rays proceeding from f' are refracted towards r, and appear as if they had emanated from r'. And so on to other cases.

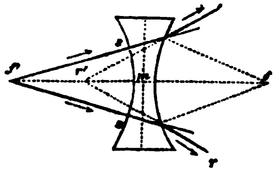


Fig. 34.

The foci of lenses may be readily found by the methods of trial explained at page 146, &c.

IMAGES OF OBJECTS FORMED BY LENSES.

23. *Convex lenses.* — If the object N S lie beyond the principal focus, as shown in Fig. 35, the image $n\ s$ will be inverted. If the object be very remote, as in the case of the sun, then the image will be formed in the principal focus f; in this case the image will be very small. If the

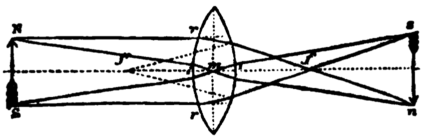


Fig. 35.

distance of the object be equal to twice the principal focal distance, the image will be at the same distance on the other side of the lens, and of the same size as the object.

If the distance of the object be still further diminished, yet not within

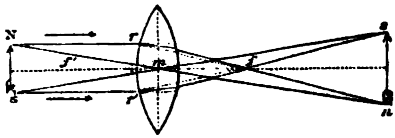


Fig. 36.

the principal focal distance, the image will recede from the lens, and its dimensions will be increased accordingly, as shown in Fig. 36.

If the object N S be brought within the principal focal distance, as shown in Fig. 37, an eye at the focus f will see an enlarged image of the

object at *n s*. In this case the refracted rays do not cross each other, and hence the image is seen erect.

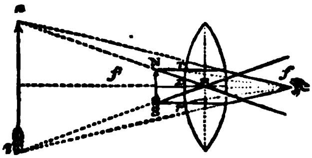


Fig. 37.

Convex lenses are called MAGNIFYING GLASSES, because they thus increase the apparent size of objects viewed through them.

24. *Concave lenses.* — These lenses diminish the apparent size of objects; hence they are called DIMINISHING GLASSES.

An object N S, (see Fig. 38,) viewed from the point *f*, will present a small image *n s* in the virtual focus.

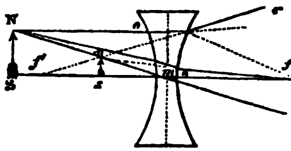


Fig. 38.

All the phenomena relative to convex and concave lenses are precisely analogous to those produced by concave and convex mirrors.

25. *Distortion of images produced by spherical aberration.* — The images of objects produced by spherical lenses and mirrors are only true for the rays which lie near to the axes. The rays which fall at a distance from the axes produce distortions in the images, which have been called spherical aberrations. In order, therefore, to produce a tolerably correct image, it is necessary that the extreme rays falling upon the lenses, or upon the mirrors, as the case may be, should be excluded from the other rays forming the picture.

There are other devices for effecting this purpose, which would be foreign to the object of this work to explain very minutely.

Descartes discovered that a concave-convex lens, A L *a* L, (Fig. 39,) having for its convex surface a portion of an ellipse, could be made so as to correct any spherical aberration; and Sir J. Herschel discovered that the same might be effected by two lenses, A B and C D, (Fig. 40.)

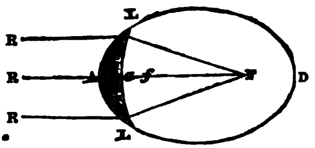


Fig. 39.

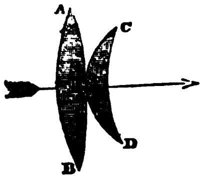


Fig. 40.

26. ***Caustic curves formed by reflection.*** — The rays of light reflected from the different points of a concave reflector M B N, (Fig. 41,) cross one another at particular points, and thus a luminous curve of reflected

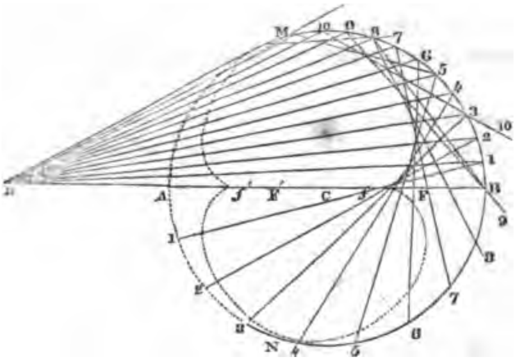


Fig. 41.

light, known by the name of the *caustic curve*, is formed. R 1, R 2, R 3, &c., are the incident rays proceeding from the luminous point R, and 1 1, 2 2, 3 3, &c., are their respective reflected rays; the luminous intersections form the caustic curve M F N.

To observe this curve, place a lighted candle at a little distance from a basin about one half full of milk; then a luminous curve will be seen upon the surface of the milk.

OPTICAL INSTRUMENTS.

THE HUMAN EYE.

27. The eye is a lens of the most delicate and elaborate construction. The eye is so constructed that it forms images

of external objects upon a thin screen of nerves communicating with the brain, and thus the sensation of vision is produced. There is nothing in nature which more fully demonstrates the existence of a great and beneficent Creator than the adaptation of the human eye to the purposes for which it is designed to serve. Let us look more minutely into the construction of this wonderful organ.

The eye is nearly spherical in figure; it consists of several membranes or coats, the anterior or front portions of which are transparent, so as to admit the rays of light proceeding from external objects into the interior of the eye. These coats enclose two colorless fluids or humors, separated from each other by membranes; the anterior portion being called the *aqueous humor*, and the posterior portion the *vitreous humor*. In the centre of this partition is a circular aperture, or hole, for the admission of light, called the *pupil* of the eye, behind which is a double convex lens, called the *crystalline lens*. Opposite to this lens is the *optic nerve*, which extends itself over the inner surface of the eye. The eye is surrounded by bones, and is moved by various muscles. The optic nerves of both eyes unite in a common nervous cord which communicates with the brain.

Fig. 43 represents a front view of the eye; and Fig. 42 a sectional view of it. The same letters of reference are used in both figures.

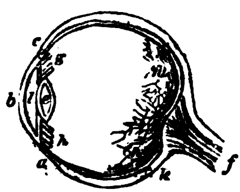


Fig. 42.

Fig. 43.

a k d c, the outermost membrane, is called the *Sclerotic coat*: it forms the white of the eye; *a b c*, the projecting transparent part, is called the *Cornea*; *e* is the *Crystalline lens* suspended between the *Ciliary Processes* *g h*, which divide the eye into two chambers, *l* and *g m n h*; the smaller and anterior portion *l* is filled with the *Aqueous humor*, and the larger

and posterior portion with the *Vitreous humor;* the former humor is like water, and the latter somewhat like a jelly, but both are colorless and highly transparent, and have about the same refractive powers as water, which is also the case with respect to the crystalline humor. *g m n h* is the *Choroid coat,* lining the whole of the interior surface of the sclerotic coat, in the form of a black slimy pigment or paint, to prevent any reflection of light taking place within the eye. Between the crystalline lens and the cornea is the *Iris k a l c,* which gives the peculiar color to the ring of the eye, in the middle of which is the *Pupil l,* which has the power of expanding and contracting to suit the intensity of the light. *f* is the *Optic Nerve,* which passes through the sclerotica and spreads itself over this coat in a reticulated form *m n,* or in the form of network, and is called the *Retina.* The nerves of the two eyes, as we have already observed, unite in a common nervous cord which communicates with the brain.

Now, when rays of light from any luminous object fall upon the eye, they pass through the pupil, and then become refracted by the crystalline lens in the same manner as by any other double convex lens, and then converge to a focus at the retina, where a *small inverted* image of the object is formed, which, acting on the fine network of nerves, produces the sensation of vision. It must be observed that the aqueous and vitreous humors also influence the refraction of the light.

When the lenses of the eye are too round, or, it may be, too dense, the rays of light are brought to a focus before they reach the retina: this takes place with *short-sighted* people; on the contrary, when the lenses are too flat, or too thin, the focus of the rays lies beyond the retina: this takes place with aged people, who are said to be *long-sighted.* To correct the focus of vision, short-sighted persons use concave glasses, and, on the contrary, long-sighted persons use convex glasses.

An object appears less and less as its distance from us is increased. Thus the arrow at A B (Fig. 44) will appear larger to the eye E of a person than it would do at D C. If the apparent lengths of the arrow in these two positions be measured by means of a pencil or little rod, we shall find that the arrow at A B will appear of the size *a b* on the pencil, whereas the arrow at D C will appear only of the size *d c* on the pencil.

In judging of the actual size of an object, we always take into account the distance at which it is seen.

Thus, although a boy near at hand may *appear* to us larger than a

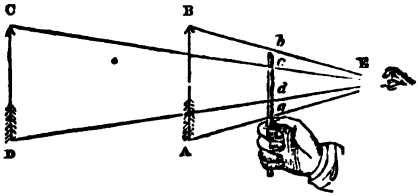


Fig. 44.

man at a distance, yet we always form a correct idea of their relative dimensions by making an allowance for the effect of distance.

We form a judgment of the distance of an object by the number and size of the intervening objects, and by the distinctness or indistinctness of its outline.

The spire of a church, as it appears in the far horizon piercing the sky, may be very lofty, or it may be scarcely higher than an ordinary building; but there are men and carriages, fields and cattle, forests and houses, hills and valleys, between us and that spire, and, besides, the windows in its tower are so indistinct that they can scarcely be distinguished; from all this we conclude that the spire is a great distance off, and that it is very lofty. A man seen through a fog sometimes appears to us like a giant; how is this? The fog, while it throws, as it were, a veil over the intervening objects, causes the object to appear indistinct, and thereby gives us a false impression with respect to its actual distance; that is to say, the fog causes us to believe that the man is at a greater distance from us than he really is, and thus we are led to assign to him an unusual magnitude. We make the same allowance for distance, &c., with respect to the objects represented in a picture, that we do when looking at the actual objects.

The angle formed by the rays of light passing from the top and bottom of an object to the eye is called the *visual angle* or the *optic angle.*

Thus the visual angle of the arrow at A B (see Fig. 44) is the angle A E B; whereas the visual angle of the arrow at D C is the angle D E C, where it will be observed that the visual angle formed by an object becomes less and less as the object recedes from the eye; or, what amounts to the same thing, the apparent magnitude of an object is in proportion to its visual angle.

In like manner, the traveller at b' d' will have the same apparent

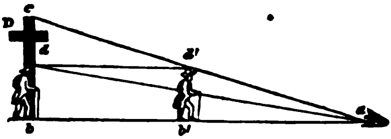


Fig. 45.

magnitude to the eye at *a* as the distant cross *d*, because the visual angles b' *a* d' and *b a d* are equal to each other.

In order to understand the way in which the eye receives impressions of objects, let us suppose that, in Fig. 46, K represents a section of the human eye, P the *pupil* in front, E the *crystalline lens*, in which all the rays are refracted and cross each other, *k q* the concave surface of the back of the eye, called the *retina*, on which the image of the object is projected; moreover, let us suppose that the eye of the person is looking at the cross A B C D, and that Q H O N represents a picture frame in which a pane of glass is inserted, having its surface coated with gum arabic so that chalk lines may be traced upon it, giving the picture *c b d a* of the cross: then rays of light will proceed from every part of the cross C B to the eye, or, what is the same thing, from every part of the picture *c b* to the eye, and will form the inverted image *m p* of the cross upon the retina; thus it will be understood that the object and its picture would form the same image upon the retina, for the point *b* inter-

Fig. 46.

cepts the view of B, *c* that of C, *a* that of A, and so on. Now, if we move the cross B C to F G, the picture *f g* on the glass, as well as the image *k q* upon the retina, would be much larger; thus it appears that *the image on the retina is larger or smaller as the object advances to or recedes from the eye of the spectator.*

When an object is brought too near the eye, the angle of vision and

the image of the object become so enlarged that the image is thrown beyond the retina, which occasions us to see the object indistinctly. Persons of ordinary vision cannot see objects distinctly when they are within the distance of six or eight inches from the eye.

THE MICROSCOPE.

28. The microscope magnifies the images of minute objects, and enables us to see them with greater distinctness. This is effected by *enlarging the visual angle;* for, as we have shown, every object appears larger according as we increase this angle.

The Single Microscope.

29. The single microscope consists of a single convex lens *m*, with a very short focal distance. An eye at *a* (see Fig. 47) would see the arrow *b c* under the visual angle *b a c;* but when the lens *m* is interposed, it is seen under the visual angle B *a* C, and hence it appears much enlarged, as shown in the image B C. The principles of refraction upon which this depends have already been explained.

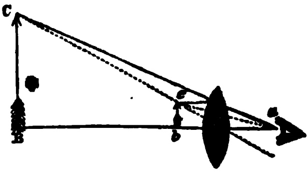


Fig. 47.

In order to see the image distinctly, it is of course requisite that the object should be placed in the focus of the lens.

Concave mirrors may be also used as microscopes. (See Fig. 19.)

The Compound Microscope.

30. The compound microscope consists of two or more convex lenses, or of a combination of lenses and concave mirrors.

Fig. 48 represents a compound microscope consisting of two convex lenses B and C. The first lens B is called the *object glass*, and the second C the *eye glass*. *a b* is the object; a^1 b^1 the inverted magnified image formed by the lens B; A the eye of the observer; a^2 b^2 the image magnified again by the lens C, and seen under the *enlarged visual angle* a^2 A b^2. Now, if we suppose the lens B to have a magnifying power of 25, — that is, if the image a^1 b^1 equals 25 times *a b*, and the lens C to have a magnifying power of 4, — then the total magnifying power of the microscope will be 4 times 25, or 100 — that is to say, the image of

the object will appear 100 times the size of the object, and the visual

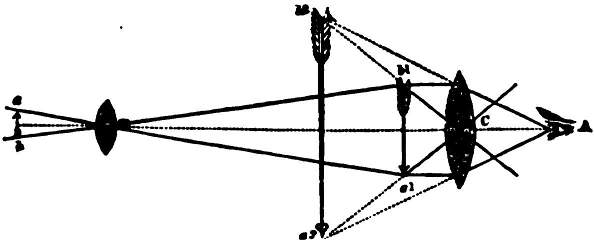


Fig. 48.

angle a^2 A b^2 will be 100 times the visual angle which the object itself would form with the eye at A.

The microscope enables us to see the structure of various minute objects. The drawings shown in Fig. 49 represent the appearance of some minute objects when seen through a tolerably good microscope. A represents the wing of a small insect called *menelaus*; B and C the hair of the bat; and D and E the hair of the mouse.

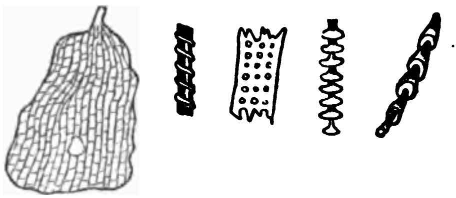


Fig. 49.

Sometimes mirrors are placed beyond the objects, to throw a greater amount of light upon them.

THE TELESCOPE.

31. Telescopes are used to magnify the images of distant objects; and this is done in the same manner as in the microscope, viz., by *enlarging the visual angle* at which they are seen.

There are two kinds of telescopes used — refracting telescopes and reflecting telescopes.

Refracting Telescopes.

32. The *astronomical telescope* is represented in Fig. 50. It consists of two convex lenses, C and B, of unequal size and focal length. The eye glass B has a much greater magnifying power than the object glass

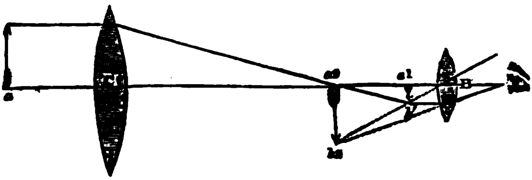


Fig. 50.

C, which is just the reverse of what is observed in the construction of the compound microscope represented in Fig. 48; the distance of the lenses from each other is usually equal to the sum of their focal lengths; the eye glass B is fixed in a sliding tube for the purpose of adjusting the focal distance between the two lenses to suit the varying distance of objects. *a b* is the distant object; *a' b'* its image formed by the lens C; B the eye glass which magnifies this image, so that it is seen by the eye A magnified at a^2 b^2.

The *night glass* is similar in its construction to the astronomical telescope.

33. The *terrestrial telescope* is represented in Fig. 51; it usually consists of four convex lenses, L, O^1, O^2, and O^3; it may, therefore, be regarded as a double astronomical telescope. These instruments show objects in their natural position. The lens L has a great focal length; O^1, O^2, and O^3 are three double convex eye glasses, having short equal focal distances set in the same sliding tube, so that the posterior focus of one lens may exactly coincide with the anterior focus of the next.

This sliding tube enables the observer to adjust for the focus of the field glass L.

34. The *Galilean telescope* is represented in Fig. 52; it consists of a convex object glass L and a plano-convex eye glass O. The inverted image *a' b'* which would be formed but for the lens O,

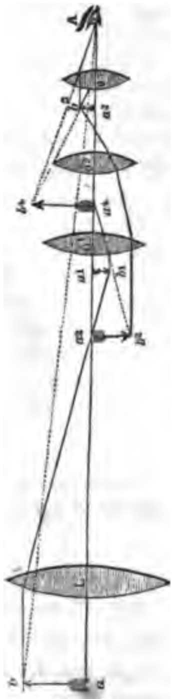


Fig. 51.

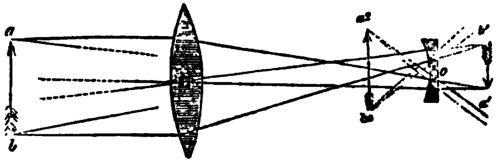


Fig. 52.

which by its refraction causes the rays to diverge from one another, and thereby forms the erect image a^2 b^2, which, of course, is seen by the eye at an enlarged visual angle. This instrument is now chiefly used as an *opera glass*.

Achromatic Lenses.

35. The instruments just described have two great defects: (1.) The defect arising from spherical aberration; (2.) The defect arising from the colored light produced by the prismatic decomposition of the light. (See page 153.) In order to remedy these defects, Dolland invented what are called achromatic lenses.

The achromatic lens represented in Fig. 53 consists of a plano-concave flint glass fitted on one face of a double convex crown glass.

Fig. 53.

Light, upon passing through a glass lens, is *dispersed* — that is, the light is separated into different colored rays. Now, crown and flint glass differ considerably in their *dispersive* powers, and at the same time differ very little in their refractive powers; hence the contrivance of the achromatic lens simply consists in making the dispersive power of the one glass exactly to counteract the dispersive power of the other, and thereby to destroy the effect of what is called chromatic aberration.

Fig. 54 represents the achromatic eye piece now in general use in all good achromatic telescopes for land objects. It consists of four lenses,

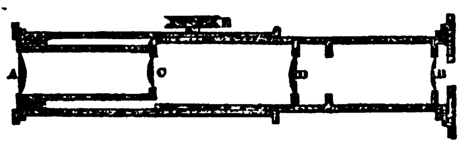


Fig. 54.

A, C, D, and B. A is very nearly a plano-convex lens; C a meniscus; D a nearly plano-convex lens; and B a double convex lens.*

* For the radii and distances of these lenses, the reader may consult Brewster's Optics.

Craig's Achromatic Telescope.

36. This is the largest instrument of the kind that was ever executed. The achromatic object glass is 24 inches in diameter, and has a focal distance of 76 feet. The manner of fitting up this magnificent instrument is shown in Fig. 55. The telescope is suspended on the side of a strong

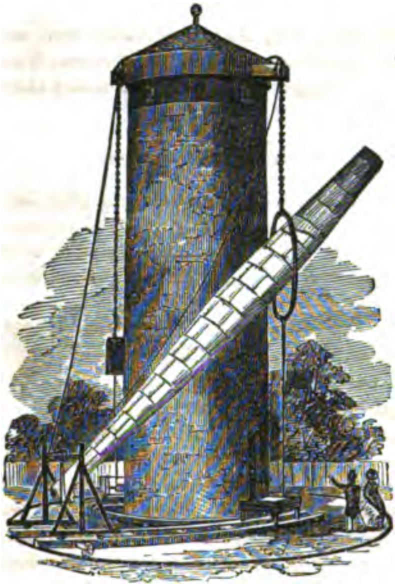


Fig. 55.

tower, 64 feet high and 75 feet in diameter. The length of the main portion of the tube is 76 feet; and, with the eye piece at the smaller end and the dew cap at the greater end, the total length of the telescope is 85 feet. The lower extremity of the tube rests upon a wooden frame standing on wheels, which run on a circular railway going round the tower at the distance of about 15 feet from it, so that the instrument admits of being readily directed to any portion of the heavens.

REFLECTING TELESCOPES.

37. The *Gregorian telescope*, represented in Fig. 56, consists of two concave mirrors or specula *s* and S S, with their concave surfaces facing

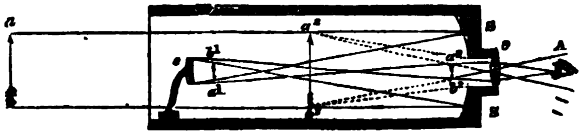


Fig. 56.

each other, and a double convex eye glass *o*, the whole being fitted in a metallic tube. *a b* is the distant object; a^1 b^1 its inverted image, formed by the large concave mirror or speculum S S; this image is again reflected by the small mirror *s*, and thus forms the erect image a^2 b^2, which is magnified by the lens *o* into the image a^3 b^3, when observed by an eye at A.

38. The *Newtonian telescope*, represented in Fig. 57, consists of a large concave mirror S and a small plane mirror *p* placed obliquely to

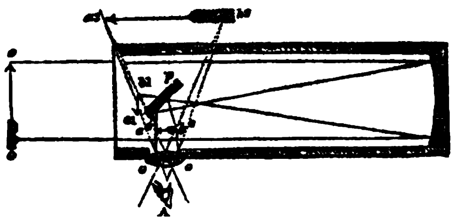


Fig. 57.

the direction of the axis of the tube, (at an angle of 45°,) and a magnifying lens *o* placed in the side of the tube.

39. *Herschel's telescope*, represented in Fig. 58, has only one concave

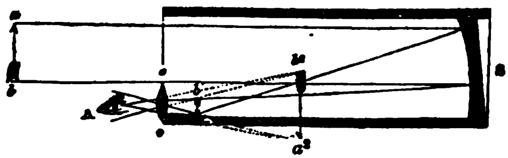


Fig. 58.

mirror S; this mirror is inclined to the axis of the tube in such a manner as to throw the inverted image $a' b'$ down to the focus of the eye glass *o o*.

The speculum of Herschel's largest telescope was 4 feet in diameter, with a focal distance of 40 feet. A much larger one has recently been constructed by LORD ROSSE, in Ireland. The speculum is 6 feet in diameter, with a focal distance of 54 feet. The diameter of the tube is 7 feet, its length is 56 feet. The whole weight is over 14 tons.

THE CAMERA OBSCURA.

40. The *Camera Obscura*, or *dark chamber*, in its most simple form, is nothing more than a dark room with a hole in the window shutter, in which is placed a convex lens of about two feet focal length. A sheet of white paper is placed vertically behind the lens, at its focus, and then an accurate picture of all the objects seen from the window will be depicted upon the surface of the paper, which delights and surprises every person that beholds it. In order to obtain a perfect picture, the ground on which it is received should be hollow, and a portion of the sphere whose radius is the focal distance of the lens; it is customary, therefore, to make this ground of plaster of paris.

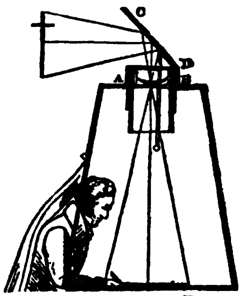


Fig. 59.

In order to enable a person to copy this picture, it should be received upon a horizontal sheet of paper. This is readily effected by means of a plane mirror C D, (see Fig. 59,) placed at an angle of 45°, to reflect the rays down upon the lens A B, which throws down the picture upon the horizontal table E F placed in the focus of the lens. The draughtsman introduces his head through an opening made in one side of the frame, and his hand, holding the pencil, through another opening, care being taken that no light is allowed to fall upon the picture. The application of the camera obscura to photography has rendered it one of our most useful optical instruments.

MAGIC LANTERN.

41. The magic lantern is an obvious application of a microscope. L (Fig. 60) is a powerful lamp in the focus of a concave mirror M N, placed in a dark lantern; A B is a fixed tube containing a hemispherical

illuminating lens A, and a convex lens B; C D is an opening between the lenses A and B, for receiving the sliders on which the pictures are

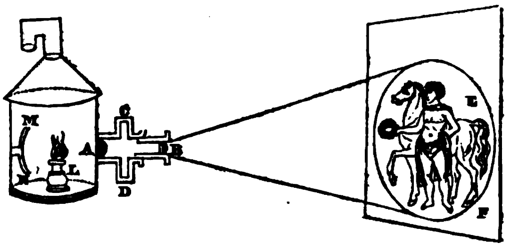


Fig. 60.

painted with highly colored transparent varnish. The light of the lamp is reflected by the mirror M N upon the lens A, which further concentrates the light upon the picture on the slider; and this picture is thrown, very much enlarged, upon the screen E F, placed in the focus of the lens. The lens B is fixed in a sliding tube, so that by pulling it out or pushing it in, a distinct picture of the object, on the slider, may be formed, of any size, within certain limits, upon the screen E F.

The *solar microscope* is merely a magic lantern, where the light of the sun is substituted for the light of the lamp.

The Stereoscope.

42. When we view any solid object, such as a statue, with both eyes, each eye sees the object differently, and two dissimilar pictures of the object are painted on the retinæ. But each two corresponding points of the two pictures are depicted at the same place on the optic nerve, so that the eyes, uniting each pair of points in succession, give the brain the impression of a solid. Now, by inverting this process, that is, by making two pictures of a solid, as seen by each eye, and uniting them upon the retinæ by squinting, so that the one picture may, as it were, be laid upon the other, the combined pictures will give to the mind the impression of a solid, seen exactly as in nature. This forms the principle of the stereoscope.

Brewster's Stereoscope. — This instrument is represented in Fig. 61. A and B are two eye tubes, containing each a semi-lens, with their curved sides turned towards each other, so that by looking through their edges, objects in their focus are so refracted that the one picture can be placed above the other.

If we now place the annexed drawings of a six-sided pyramid A and

B in the bottom of the box by sliding them in at C D, and look into the instrument, with the right eye at A and the left at B, we shall see a

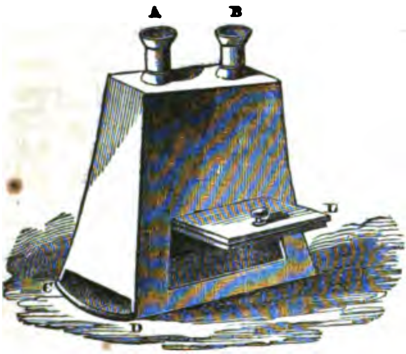


Fig. 61.

solid pyramid with its apex *rising* to the eye. If the two figures had been united by squinting, they would have produced a hollow pyramid.

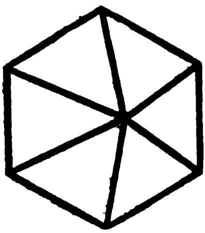


Fig. 62.

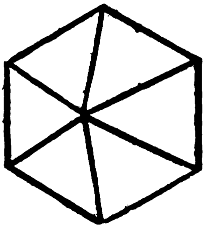


Fig. 63.

Here the left hand drawing is the view which the pyramid would present to the left eye, and the right hand drawing the view which the pyramid would present to the right eye. Any solid object may be treated in the same manner.

PHENOMENA OF COLOR.

43. A ray of solar light is formed by the union of seven different colored rays. This may be proved analytically as well as synthetically — analytically by transmitting a ray of

white light through a glass prism, when it becomes resolved into seven different colored pencils of light, which have been called the prismatic colors; and synthetically, by showing that white or colorless light is produced by the union of the different colored pencils of light.

Some transparent bodies only transmit certain colored portions of light, as, for example, common bottle glass only transmits the green rays of light; blue glass only transmits the blue rays; and so on.

Nature presents us with a magnificent analysis of solar light in the rainbow, where the seven prismatic colors may be distinctly seen.

The surfaces of bodies decompose light by reflection. The surface of a rose leaf reflects the red light, and absorbs all the other colored rays; the surface of gold reflects the yellow light, and absorbs all the other colored rays; and so on. Thus the many-colored tints which we see in the objects around us are familiar examples of the analysis of light.

THE SOLAR SPECTRUM.

44. Newton first decomposed solar light by means of a solid piece of glass bounded by three plane surfaces, and commonly called the prism. The success of this experiment depended upon the fact, that the primary or simple rays, of which pure white light is composed, possess different degrees of refrangibility. He conducted the experiment in the following manner:—

A sunbeam S H is admitted into a dark room through a hole H made in a window shutter E F; a prism A B C is interposed so that the ray

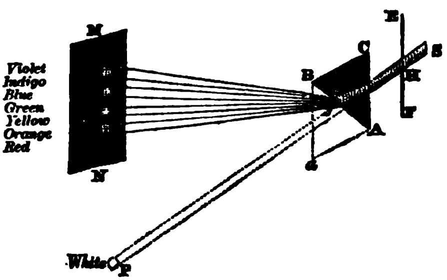


Fig. 64.

shall pass obliquely through two faces, and be refracted by both. The refracted ray is received upon a sheet of white paper M N, and, instead of a spot of white light, there is formed upon the paper an oblong colored surface K L, composed of the seven primary tints, called the *prismatic* or *solar spectrum*, as shown in Fig. 64.

These different colored rays do not admit of any further analysis; but on causing them all to be united, the seven colors disappear, and white light is again formed. White light, therefore, is a mixture of seven primary rays of different colors, — *red, orange, yellow, green, blue, indigo,* and *violet.* The separation of these primary or simple rays from one another, depends upon a difference in their refrangibility in passing through the prism; thus the violet ray is most refracted, and the red ray is the least refracted.

45. The different portions of the solar spectrum have three distinct properties, in relation to *light, heat,* and *chemical action.* The most luminous portion is at the middle of the yellow light, the most heating at and beyond the red, and the greatest chemical intensity is found to be between the violet and indigo.

Fig. 65 exhibits these relative intensities by three curved lines, one showing the curve of luminous *intensity,* another the heating or thermal

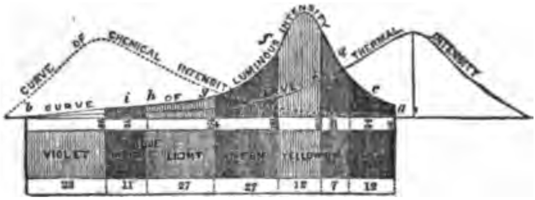


Fig. 65.

intensity, and the third the chemical intensity, or the power which light has in effecting chemical changes.

46. Brewster considers that white solar light is composed of only three primary rays, viz., red, yellow, and blue; for the admixture of these three colored rays will produce white light, as shown in Fig. 66. These are called the three fundamental colors.

Each of the seven prismatic rays has some other colored

ray, called its *complementary* ray, with which if it be combined, white light will be produced.

Fig. 66 shows the three fundamental colors, red, yellow, and blue, overlapping each other. Where all three overlap one another, white is produced; where the yellow and blue overlap, green is produced, and, therefore, green and red will produce white light, so that green and red are complementary; and so on to other cases which may be readily cited from the representation given in the figure. Orange, violet, and green, according to Brewster, are called secondary colors; while red, yellow, and blue, are the only primary colors; and the indigo of Newton's spectrum is supposed to lie between the shades of the violet and the blue.

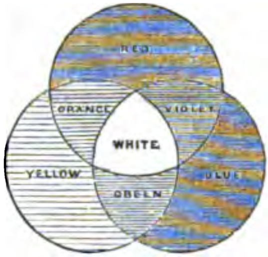


Fig. 66.

THE RAINBOW.

47. The brilliant colors of dew drops, produced by the refraction of the sunbeams, form a subject of interest to every person. The beautiful arch of the rainbow, depending upon the same cause, is not less a matter of interest to even the most uneducated observer. The formation of the rainbow may be readily explained on the principle of prismatic refraction and dispersion.

The drops of rain decompose the sun's light in the same manner as the prism of glass. Let D represent a drop of rain, (see Fig. 67 :) *a b*, a ray of light falling upon the drop, is refracted in the direction *b c;* it is then reflected in the direction *c d*, and upon passing out of the drop at *d* it undergoes the prismatic dispersion: the red ray, being the least refracted, takes the lowest direction *d r*, and, the violet ray, being the most refracted, takes the highest direction *d v;* hence arise the prismatic colors. Now, in Fig. 68, let D represent the same drop, and D′ another drop a little below the first; then the same prismatic colors will be produced by this second drop, and at some point *o* the red ray of the first drop will meet the violet ray of the second drop; and a spectator, with his eye at *o*, will see the red ray from the first

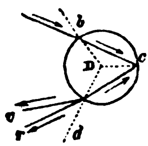


Fig. 67.

drop and the violet ray from the second drop, and from the drops lying between these two extremes he will see the intermediate prismatic colors,

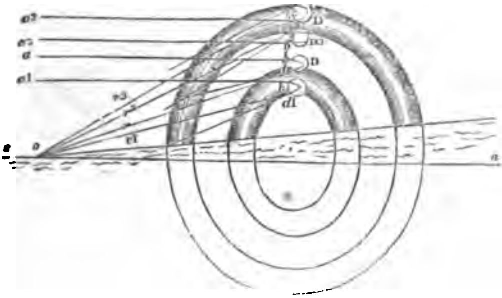


Fig. 68.

and therefore between *d* and *d'* he will see a complete spectrum. Now, let *s u* be a straight line passing through the centre of the sun and the eye of the observer at *o*, which will of course be parallel to the rays incident upon the drops. Conceive the angles *d o u* and *d' o u* to be turned about *o u* as an axis: then the drops D and D' will revolve in a circle, and within this circle all the prismatic colors will obviously be arranged in the same order as that which we have just described; hence the prismatic colors will appear to arrange themselves in this arch, which is called the primary rainbow.

The secondary rainbow is a fainter arch, frequently lying exterior to the primary one. The formation of this secondary arch may be explained exactly in the same manner, with this exception, that the refracted light undergoes two reflections within the drop in the place of one, as shown in Figs. 68 and 69.

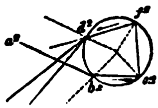


Fig. 69.

UNUSUAL REFRACTION OF LIGHT, AND ATMOSPHERIC PHENOMENA DEPENDING UPON IT.

REFRACTION OF A FLUID OF VARYING DENSITY.

48. Into a square vial (Fig. 70) pour some clear sirup, and above pour some clear water, which will gradually mix with the sirup; hold a card, with the word *sirup* written on it, in an erect position, behind the vial; then the writing will appear, in its erect position, when seen through the

Fig. 70.

Fig. 71.

pure sirup, but it will appear inverted when seen through the mixture of sirup and water. A similar phenomenon will be produced by pouring spirits of wine upon the water, as shown in the figure.

This simple experiment will enable us to account for some curious cases of unusual atmospheric refraction, or *mirage*.

Sometimes two distinct images of a ship, whose topmast A only is seen above the horizon, will in certain states of the atmosphere appear in the air as represented in Fig. 71, where one image C is erect, and the other B is inverted.

In order to account for these appearances, let S P (Fig. 72) represent

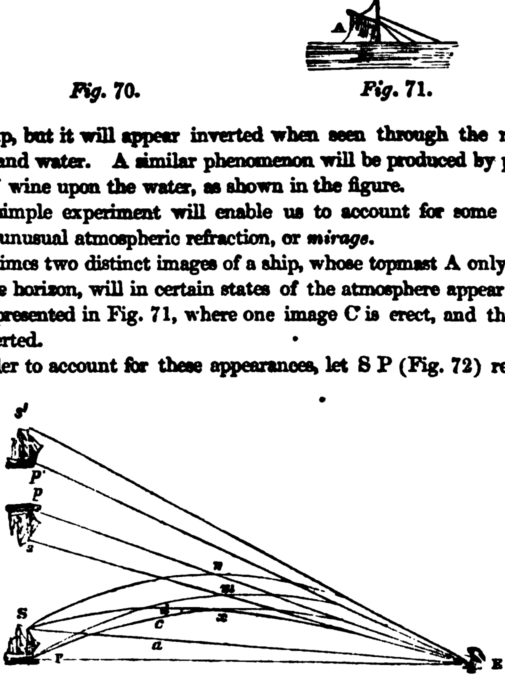


Fig. 72.

the object; E the eye of the observer; p and p' the images seen in the air. Now, the coldness of the sea may cause the air at the level a to be very much denser than the air at the level c or d; in this case, the re-

fractive power at *c* or *d* will be much less than at *a*; the consequence of this is, that rays S *d* P *c* which, under a uniform state of density of the air, never would reach the eye at E, will be bent into the curve lines S *d* E, P *c* E, in passing from the rare to the dense medium; and if the difference of density is such that the higher rays S *d* cross the lower rays P *c* at any point *x*, then the higher rays will be seen in the direction E *s*, (where E *s* forms a tangent to the curve S *d x* E at the point E,) and the lower rays in the direction E *p*; and thus the image of the ship will be seen *inverted* in the air. In like manner the rays S *n*, P *m*, may be refracted to meet the eye E without crossing each other; then the higher rays S *n* E will be seen in the direction E *s'*, and the lower rays P *m* E will be seen in the direction E *p'*, and thus the image of the ship, in this case, will be seen in its erect position *p' s'*. The state of the air may be such as to exhibit only one of these images.

49. The subject of *halos* may be ranked amongst the optical phenomena of the atmosphere. The name halo is given to all those luminous appearances which are seen surrounding the sun or the moon.

One of the most common phenomena of this kind is the divergence of the solar beams, represented in Fig. 73.

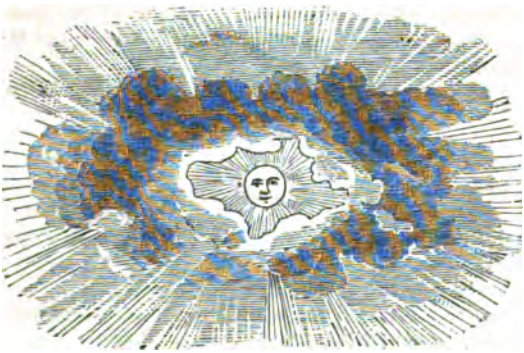


Fig. 73.

This phenomenon frequently occurs in summer, when the sun is near the horizon. It is caused by certain portions of the sun's beams radiating through the openings of the surrounding clouds, while other portions of his beams are obstructed by the denser parts of the clouds.

DOUBLE REFRACTION.

50. Some crystals possess the curious property of *double refraction* — that is, of making one object appear double.

The most common crystal of this kind is Iceland spar, which usually has the shape of a solid rhomb, or six-sided parallelopiped A B D C X, represented in Fig. 74.

Place a rhomb of Iceland spar over a black line M N drawn upon a sheet of paper; look at this line through the upper surface of the crystal with the eye at R: then the line M N will probably appear double; if it does not at the first trial, turn the crystal round until you distinctly see two black lines in the place of one.

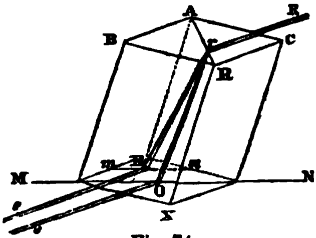


Fig. 74.

Place a black spot at O, or prick a pin hole in the paper; the spot will appear double, as at O and E; turn the crystal round, and the two images will be seen apart from each other: the one E will appear to revolve round the other O. The ray O *r* is called the *ordinary* ray of refraction, and E *r* the *extraordinary* one.

The ray of light, after separation into two distinct pencils in this manner, is said to be *polarized*. These polarized rays possess certain peculiar properties, which distinguish them from the ordinary rays of light.

POLARIZED LIGHT.

51. Light is polarized by reflection.

Let A B C D and *a b c d* be two glass reflectors having their backs coated with black varnish; place them, as represented in the figure, so that the rays of light R Q proceeding from the candle R may be reflected from the mirror A B C D in the line Q P, and that these reflected rays may undergo a second reflection from the other mirror *a b c d* in the line P E. Now, if the two mirrors were both placed vertically, the reflection of the light of the candle from the second mirror would suffer very little or no diminution; but when the plane of the second mirror is placed at right angles (or nearly at right angles) to the plane of the first mirror, the image of the candle reflected from the second mirror is so dim that it can scarcely be distinguished; and if the reflections are made at the

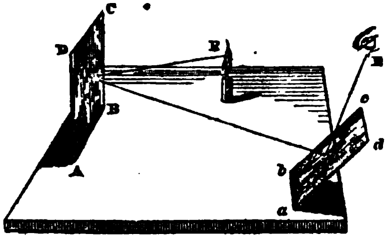


Fig. 75.

proper angles, the ray Q P will not be at all reflected from the mirror *a b c d.* The reflected ray Q P is said to be *polarized* by reflection. The polarizing angle of glass is about 56°, that of water is about 52°, and so on to other reflecting surfaces.

Having placed the mirror A B C D so that the ray Q P shall be reflected at the angle of 56°, elevate or depress the angle of the second mirror *a b c d* until you have hit upon that position where the image of the candle just vanishes; then you will find this angle to be about 56°, the polarizing angle of glass at which the polarized ray will not undergo a second reflection. Blow upon the glass; the light will appear again. Why? Because the polarizing angle of water is different from that of glass; the moisture on the glass soon disappears by evaporation, and then the image of the candle again vanishes.

52. Fig. 76 represents an instrument constructed on the principle just explained. C D and D G are brass tubes, the one capable of sliding

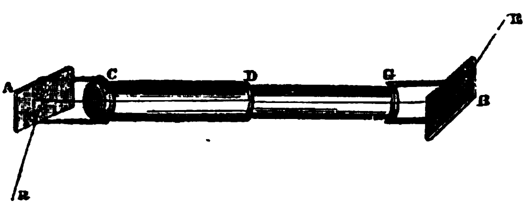


Fig. 76.

and turning within the other; A and B are the glass mirrors fixed to the two tubes at the polarizing angles; R *r* an incident ray of common light; *r s* the line of its reflection from the mirror A through the tube; *s* E the line of reflection from the mirror B; then, when the tube D G is turned round so that the plane of the mirror B is at right angles to

the plane of the mirror A, the ray *r s will not suffer reflection* from B. When the tube D G is turned round so as to bring the plane of the mirror B parallel to that of A, then the reflected ray *s* E will appear of its proper or usual degree of brightness.

Exp. 1. Let the incident rays R Q (Fig. 75) proceed from the light of the window; place a thin plate of mica between the two mirrors so as to intercept the polarized rays Q P; look in the direction E P, and you will perceive the dark reflector lighted up with the most splendid colors, more especially if the plate of mica varies in its thickness. Turn the mica round, and the colors will pass through all the changes of the prismatic light. A similar effect will be produced by turning the reflector *a b c d* round upon Q P as an axis.

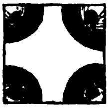


Fig. 77.

Exp. 2. In like manner, place a piece of glass, to which a crystalline structure has been given by rapidly cooling it, between the reflectors: then the glass will present a brilliant and symmetrical figure having the appearance represented in Fig. 77. Turn the mirror *a b c d* round on Q P as an axis, until it becomes parallel to the other mirror A B C D; then the colored figure of the crystalline glass will assume another perfect form, which is represented in Fig. 78, the colors in the one being complementary to those in the other.

Fig. 78.

These crystalline pieces of glass may be got at any philosophical instrument maker's shop; but, without incurring this expense, the experiment may be performed in the following manner: —

Bind a few square plates of window glass together, and place them between the mirrors, as in the last experiment, on a hot metal plate; look in the reflector *a b c d;* a curious progressive change will be seen to take place in the glass plates, when at length the symmetrical figure shown in Fig. 77 will be formed.

53. Light is polarized by a series of ordinary refractions.

When a ray of light R *r* (Fig. 79) undergoes refraction through a series of glass plates 1, 2, 3, . . ., the refracted ray *f g* becomes polarized, and possesses all the properties which have been described in relation to the polarized light of reflection. The incident angle of perfect polarization depends upon the number of the plates; thus,

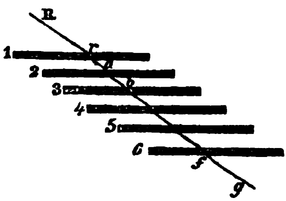


Fig. 79.

when there are eight plates, the incident angle is about 79°; and when there are twenty-four plates, the incident angle is about 60°, and so on.

Now, since a bundle of glass plates acts upon light in the same manner as the polarizing reflectors used in the apparatus, Figs. 75 and 76, we may substitute two bundles of glass plates in the place of the two reflectors. Thus, let A and B be the two bundles of polarizing plates; R *r* the incident ray; then *s t* will be the polarized ray, which will pass through the bundle B when it is placed as in the figure, and no light will be reflected; but when it is turned round, the light *v w* transmitted through it will gradually diminish, and more and more light will be reflected, till it has turned round an angle of 90°: then there will be no light transmitted — it will be entirely reflected.

Fig. 80.

In conducting many experiments, a bundle of glass plates may be advantageously used in the place of the reflector *a b c d* of the apparatus represented in Fig. 75.

54. *Polarized Light.* — According to the corpuscular theory, a beam of common light has two polar axes, A B and C D, Fig. 81, so that all

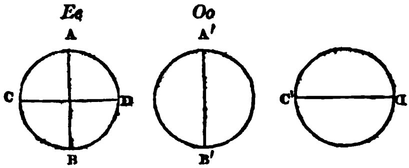


Fig. 81.

its sides have the same properties; but when this beam is polarized, it is separated into two circular beams, A′ B′ and C′ D′, with only one polar axis each, which are at right angles to each other, so that their sides have different properties.

HEAT.

55. The sense of touch is affected by heat, as our sense of hearing is by sound, or our sense of sight by light. Heat is one of the most important agents connected with animal and

vegetable life; it also performs a distinguished part in all the changes continually going on in the external world.

Free or sensible heat tends to diffuse itself equally among all surrounding bodies. The amount of sensible heat in any body is called its *temperature.* That heat which exists in a body, and which is not sensible to the touch, but which is, at the same time, essential to the peculiar form in which the body exists, is called *latent heat.*

The word *caloric* is used to express the substance of heat, in order to distinguish it from the sensation of heat. We experience the sensation of *heat* when there is an increase of temperature, and that of *cold* when there is a decrease of temperature. The sensation of cold is excited when a portion of our caloric is taken from us, and that of heat when a portion of caloric is transmitted to us.

Caloric, or the matter of heat, is subject to the same laws of radiation, reflection, and refraction as light. Heat produces many chemical changes; it also tends to destroy the cohesion of the particles composing a body, and thus produces a change in the form of bodies; thus, at a certain low temperature liquid water becomes solid ice, and at a certain high temperature it boils and passes into the state of vapor or steam. One of the most striking effects of heat is, that it causes all bodies to expand — that is, to increase in volume or bulk.

EASY COURSE OF EXPERIMENTS, WITH SIMPLE PRINCIPLES DERIVED FROM THEM.

56. Heat expanas liquids, air, and solids.

Exp. 1. *Heat expands liquids.* — Take a common vial bottle; make a mark with ink upon its neck; fill it with cold water up to this mark; plunge the vial into a basin of hot water: after a little time the water in the vial will rise considerably above the mark, thereby showing that the heat has caused the water in the vial to expand. The higher the temperature of the water in the basin the greater will be the expansion of the water in the vial.

This experiment shows the principle upon which the thermometer is constructed. This well-known instrument enables us to tell the temperature of any body.

This experiment may be performed in a more striking manner as follows: Fit a small glass tube to the cork of a bottle, as shown in Fig. 82; fill the bottle completely with cold water, and firmly insert the cork with its tube; plunge the bottle into hot water, and the liquid will rapidly rise in the small tube.

Fig. 82.

Exp. 2. *Heat expands air.* — Invert a glass A over water, allowing a little water to enter the glass, as shown in Fig. 83: pour hot water over the glass, which will cause the air within the glass to expand, and to occupy a larger space.

Exp. 3. Invert a small bottle in cold water, and introduce just so much water as will cause it to sink to the bottom; now pour hot water into the vessel, so as to raise the temperature of the air within the bottle: the bottle will rise to the surface.

Fig. 83.

The variation of heat in the atmosphere is the cause of currents of air and winds. This has been explained in Pneumatics.

Exp. 4. Perform experiments 1 and 2, given at page 107.

Exp. 5. *Heat expands solids.* — Take a decanter bottle, having a ground stopper; plunge the neck of the decanter into hot water, and there let it remain for a short time; after taking it out, insert the stopper gently, so that it may be easily taken out; allow the neck of the decanter to cool, then try to raise the stopper; it will have become so fast, from the contraction of the glass, that it requires some force to pull it out. Here the heat causes the neck of the decanter to expand; then, when the stopper is put into its place, the neck of the decanter, as it cools, contracts upon the stopper, and causes it to become fast.

If you should happen to heat the neck of the decanter so much that you cannot pull the stopper out, (a thing not at all unlikely to happen,) then you must get it out by the same means as that by which you fastened it in; that is, you must heat the neck of the bottle, so as to cause it to expand.

Many a good bottle has been broken by hastily putting in the cold stopper when the bottle was warm.

57. *Sources of Heat.* — Besides the heat derived from the

sun, we get heat from our ordinary fires, lamps, from the friction and collision of bodies, from chemical action, &c.

Exp. 1. *Heat from common flame.* — (*a.*) The degree of heat of a flame depends upon the supply of air. Place a common lamp glass over a lighted candle; the candle will burn very feebly, unless you raise the glass a little so as to admit a current of air through the tube. (*b.*) Slowly and gradually insert a burning splinter of dry wood into a small vial bottle; the portion of the splinter outside of the bottle burns, but that within the vial merely becomes carbonized, because there is not a sufficient quantity of air to burn it completely. On this principle charcoal is made.

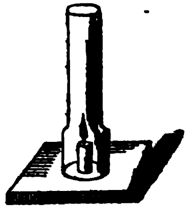


Fig. 84.

Exp. 2. *Heat from friction.* — Rub a button upon a deal board; the button will soon become quite hot.

Exp. 3. *Heat from collision.* (*a.*) Strike a spark with a flint and a steel. (*b.*) Hammer a piece of iron until it becomes hot.

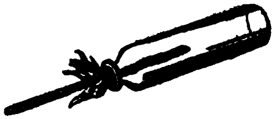


Fig. 85.

Exp. 4. *Heat from chemical action.* — (*a.*) Place a small bit of phosphorus upon a dry deal board; drop a small piece of iodine upon the phosphorus; the bodies will unite spontaneously, and will form a compound of iodine and phosphorus.

(*b.*) Pour some water upon sulphuric acid; the mixture will become intensely hot. In this case, the volume of the mixture will be less than the sum of the volumes of the two liquids. This condensation of volume is no doubt the cause of the development of the heat, for a change of volume is always attended with a change of *specific heat*, or a change of the body's *capacity for heat*.

58. *Good and Bad Conductors of Heat.*

Exp. 1. Put the end of a tobacco pipe into the fire, and at the same time put the end of a poker into the fire; after the lapse of a few minutes, touch the poker, at the distance of a few inches from the heated extremity, and it will feel quite hot; at the same moment touch the extremity of the tobacco pipe, and it will scarcely feel warm: thus showing that iron is a much better conductor of heat than the material composing the pipe.

Exp. 2. Touch the metal portion of the handle of an Italian iron;

it will feel hot; touch the wooden portion of the handle, and it will feel comparatively cool; thereby showing that iron is a much better conductor of heat than wood.

Compare the heat of the handle of a saucepan having a metal handle, with the heat of the wooden handle of another saucepan.

Exp. 3. Touch the wooden leg of a table with one hand, and the brass castor with the other; the one feels cold, the other neither hot nor cold. Here the metal, being a good conductor of heat, conveys the heat from the hand more rapidly than the wood, which is a bad conductor of heat.

Exp. 4. Touch the hot surface of a teapot through a piece of paper; you scarcely feel the heat: now touch it through a piece of tin foil or sheet lead; you instantly feel the heat. The paper is a bad conductor of heat; but the tin foil, as well as metals generally, is a good conductor of heat.

We clothe our bodies with woollen and linen, and such like materials, because they are bad conductors of heat.

Exp. 5. Fill a common porter bottle with hot water, and, after corking it up, wrap it in a dry piece of flannel; the bottle may remain in that state for an hour, without much sensible change in its heat. Here the heat is kept in the bottle by the non-conducting substance with which it is surrounded.

Exp. 6. Pour some cold water into a tumbler; carefully pour some hot water upon the top of the other; apply your hand to the lower part of the tumbler: the temperature of the water beneath is scarcely at all affected; thereby showing that water and glass are both bad conductors of heat, and, moreover, that the hot water is lighter than the cold water.

Hot water is specifically lighter than cold water, because of the expansion by heat, which causes bodies to become less dense.

Try to place cold water on the top of hot water.

Exp. 7. Nearly fill a tumbler with cold water; pour some ether upon its surface; the ether will float upon the water: ignite the ether by throwing a small piece of lighted paper upon it; the great heat at the surface of the water will not sensibly affect the temperature of the water at the lower portion of the tumbler.

Exp. 8. Take two pieces of small wire, of exactly the same length and thickness, the one being copper wire, and the other iron or steel wire; hold one in each hand, and insert their extremities into the flame of a candle; you will find that the heat will pass along the copper wire much more rapidly than it will pass along the iron wire, for the conducting power of copper is more than double that of iron.

59. *Good and Bad Radiators and Reflectors of Heat.*

Exp. 1. Place a tin plate and a piece of board within a foot and a half of a good fire; after a few minutes, the surface of the deal board will feel quite hot, but the temperature of the tin will scarcely at all be altered. What is the cause of this remarkable effect? Wood is a bad reflector of heat, and therefore it absorbs nearly all the heat which falls upon it; on the other hand, tin plate is an excellent reflector of heat, and therefore nearly all the rays of heat which fall upon its surface are reflected from it.

Exp. 2. Observe, when the sun is shining, that the panes of the window never become warm, while the wooden bars become hot.

Exp. 3. Hold a tin plate, in an inclined position, a few feet before a good fire; receive the reflected heat upon the hand; you will feel a decided increase of temperature.

Exp. 4. Try the same experiment with a deal board, or with a rough plate.

Exp. 5. Take a clean metal teapot, and a common earthen ware one; fill them both with hot water; allow them to stand for about a quarter of an hour; dip your hand into the water of each; the water in the metal teapot feels much warmer than that which is in the earthen ware one. Why? Simply because the earthen ware vessel is a much better *radiator* of heat than the metal one.

The principle which regulates the power of radiating surfaces is this: *The best reflectors are the worst radiators.* Thus, bright polished surfaces, (other things being the same,) which are the best reflectors, are the worst radiators; and rough, black surfaces, which are the worst reflectors, are the best radiators. Bad reflectors either transmit or absorb the heat which falls upon them.

Exp. 6. Cover half of one side of a piece of glass with tin foil; hold the covered side next to a good fire; place your hand on the other side; no heat will be felt on that part of the glass which is behind the tin foil, but a sensible temperature will be felt behind the other portion: here the tin foil reflects all the heat, and the glass transmits a portion of heat through it.

Now blacken the uncovered portion of the glass with soot, and a still greater difference of heat will be observed. In this case, the soot absorbs all the heat which falls upon it, and becoming thereby heated, radiates this heat to the hand.

Exp. 7. Envelop two tumblers with paper, one with black paper, the

other with silver paper; partly fill the tumblers with water, an expose them to the heat of the sun; after the lapse of a few minutes, ascertain the temperature of the water in the tumblers, by means of a thermometer; the water in the tumbler with the black paper will be found to be much warmer than the water in the other. Here, the black paper absorbs the heat, while the silver paper reflects it.

Reverse the form of this experiment by filling the tumblers with hot water; after the lapse of a few minutes, the water in the tumbler with the black paper will be found to be much cooler than the water in the other.

Here the black paper radiates the heat much more rapidly than the silver paper.

Exp. 8. Make two little fire screens, one of pasteboard, and the other of tin plate; place them about a foot before the fire, and after a few minutes try the heat which they transmit; the air beyond the pasteboard will be much warmer than that which lies beyond the tin plate.

60. Heat changes liquids into vapors, and cold condenses these vapors.

Exp. 1. When water boils in the kettle, observe the steam or vapor as it issues from the spout.

(*a*) The vapor is seen for about an inch in front of the spout; it then rises and gradually disappears by mixing with the air. The air, it must be observed, can always absorb or retain a certain portion of vapor.

(*b*) Hold a cold plate in front of the steam; it is condensed, that is to say, it is converted into water again. In a short time the plate will become quite hot, from the heat given up by the steam on its return to the liquid state. This heat is called *latent heat*, because the water after condensation has the same temperature as it had just before condensation: this latent heat is the heat requisite for maintaining water in the state of steam or vapor. Whenever a body passes from the vaporous state to the liquid state, or from the liquid state to the solid, it must give off its latent heat, and *vice versa*.

(*c*) Plunge the ball of a thermometer into the steam; the mercury will rise in the small tube until it arrives at 212°, where it will remain. Plunge the ball into the boiling water; the mercury, as before, will *stand* at 212°. Water under ordinary circumstances constantly boils at a temperature of 212°. What becomes of all the heat that is constantly passing from the fire to the water? It remains in a latent state in the steam. So long as water remains in the kettle there is no danger of it being destroyed by the heat; but the kettle will soon be cracked by the heat if it is allowed to remain on the fire after the water has

been boiled away. The evaporation of the water, by constantly absorbing the heat, prevents the metal from rising above a certain degree of heat.

(*d*) Observe the violent *ebullition*, or boiling up, of the water, as the steam issues from its surface.

Exp. 2. Boil some water in an egg shell; the evaporation of the water prevents the egg shell from being burned.

In warm, dry weather, water rises spontaneously into the air; this is called *evaporation*.

Exp. 3. Pour a little water on a plate; after a short time, if the atmosphere is in a dry state, all the water will be *evaporated*. Where has it gone? It is absorbed by the surrounding air, which has a certain capacity for retaining moisture; this capacity increases with the temperature of the air.

A drop of ether, let fall upon a plate, will be still more rapidly evaporated.

Wrap a bit of blotting paper round the ball of a thermometer; moisten the paper with water; in a short time the mercury in the tube will fall; thereby showing that the evaporation of the water produces cold.

The effect in this experiment will be more marked if spirits or ether are used in the place of water.

Let fall a drop of spirits of wine, or ether, upon the back of the hand: move the hand backwards and forwards; the liquid will be quickly evaporated, and a sensation of cold will be produced on that part of the hand where the drop was placed.

When the air is cooled down to a certain point, it deposits moisture; this is called the *dew point*.

Exp. 4. Bring a cold plate from the external air into a warm room, where there is a good fire; moisture will be instantaneously deposited upon the plate. Here the air in contact with the cold plate deposits a portion of its moisture. Take a dry tumbler into a warm room; fill the glass with cold spring water; moisture will be deposited upon the outside of the glass.

The temperature of the water just requisite for forming the deposition of moisture is called *the dew point* of the air in the apartment.

Dew is formed upon the leaves of the plants in a similar way.

When air contains all the moisture which it is capable of supporting, it is said to be *saturated* with moisture. In damp weather, the air is always saturated with moisture, but in dry, clear weather, the air is usually below this point of saturation.

The evaporation of moisture from the earth goes on more rapidly during warm, dry weather, than in cold, damp weather. When the atmosphere is warm and dry, the moisture in it is perfectly invisible; but when the atmosphere undergoes a great reduction of temperature, the moisture which is in it becomes visible, and is deposited in the form of fog, or mist, or dew, and also in the form of rain or snow. The absolute quantity of moisture which the air will sustain depends solely upon its temperature; but the process of evaporation is accelerated by the rarefaction of the air; that is to say, other things being the same, water will be much more rapidly evaporated in an atmosphere of low pressure than in an atmosphere of high pressure.

Exp. 5. *Water boils at a low temperature in a vacuum.* — Half fill a flask with hot water; boil the water until steam issues from the mouth; remove the flask from the flame and quickly cork it: the boiling immediately ceases. Pour cold water over the upper part of the flask; the boiling immediately begins again with increased violence.

Fig. 86.

Here cold appears to make the water boil; how is this? The cold water condenses the steam in the upper portion of the flask, and forms a vacuum, or at least a partial vacuum, and the water boils again because it is not subject to any pressure upon its surface. This explains why water boils at a less temperature upon the tops of mountains than it does in the plains or valleys.

When the lid of a saucepan is kept tightly down, the water boils at a higher temperature than 212°. On this principle we obtain steam in the boiler of the steam engine of a great expansive pressure.

61. Cold is produced when certain substances melt.

Exp. 1. When you form an effervescing draught, observe that the drink is very cold. Plunge the bulb of a thermometer into the mixture, and you will find that the mercury will fall several degrees. Here two crystalline substances are rapidly dissolved by water; and, moreover, the rapid escape of carbonic acid gas further aids the reduction of temperature.

Exp. 2. Mix some snow or ice and common salt together; the two solids will become a liquid, and an intense degree of cold will be produced. This is called a freezing mixture.

Exp. 3. Put a piece of ice into water; plunge a thermometer into the liquid: in a short time the thermometer will sink to 32°, the temperature at which water freezes or at which ice melts: the thermometer will stand at 32° so long as there is a particle of ice in the water.

CERTAIN LAWS AND PHENOMENA OF HEAT MORE FULLY CONSIDERED.

EXPANSION OF BODIES BY HEAT.

62. In the construction of large metal structures, a due allowance is always made for the expansion and contraction of the material from the changes of temperature. In the great tubular bridges, several inches' play are allowed for the expansion and contraction of the metal.

The following apparatus shows in a striking manner the expansion of metals by heat: —

C D is a metal rod furnished with a handle A; B a flat plate, pierced with a hole, into which the rod C D fits freely and exactly, and provided with a notch in one side exactly corresponding to the length of the rod C D when it is of the usual temperature. Now, when C D is heated in the fire, it will expand in all directions; and it will be found to be too thick to enter the hole, and its length will be so much increased that it will not enter the notch. Let the bar C D be now plunged into cold water, then it will return to its original dimensions and it will again fit the hole and the notch.

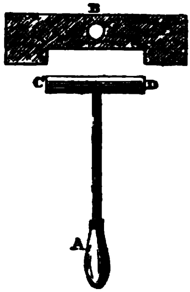


Fig. 87.

Compensation Pendulums.

63. In order that a pendulum should exactly vibrate in the same time in winter and summer, it is necessary that its length should not be altered by slight variations of temperature. Pendulums which are constructed so as to counteract the influence of changes of temperature are called compensation pendulums.

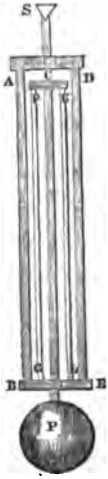


Fig. 88.

The gridiron pendulum, represented in Fig. 88, consists of two different kinds of metals, connected together somewhat in the form of a gridiron. The bob P is suspended by the iron rod P C, which is attached to the two zinc rods F G and K L terminating at the bottom in the iron frame B E D A. Now, under equal augmentations of heat, zinc expands about twice as much as iron; hence, if the length of the iron rods in this pendulum be about double that of the zinc rods, the expansion of the one metal would exactly counteract the expansion of the other. The expansion of the iron rod C P, as well as the expansion of the iron frame A D E B, carries the bob P farther away from the point of suspension S; but the expansion of the two zinc rods G F and L K brings the bob P nearer to the suspension S; and when these two expansions are equal, the distance between the bob and the point of suspension remains the same; that is, the length of the pendulum remains the same under every change of temperature.

Fig. 89.

The mercurial compensation pendulum, represented in Fig. 89, is a more simple contrivance for attaining the same end. A glass vessel B containing some mercury is suspended from the pendulum rod A C. When the rod A C expands, the distance of the vessel B from the point of suspension C is increased; but, on the other hand, the expansion of the mercury in the vessel brings the centre of gravity of the mass nearer to the point of suspension; and the proportion of the parts may be so adjusted that the effect of the expansion in one direction may exactly neutralize the effect of expansion in the contrary direction.

Thermometers.

64. These important instruments are used to measure the degree of temperature to which bodies are raised. When very high temperatures are to be measured, the instrument is called

a *pyrometer.* The change of volume which takes place in the substance employed in the instrument serves as an index to the degree of heat. The thermometer derives its name from the particular thermoscopic substance used; thus we have the common mercurial thermometer, the spirit-of-wine thermometer, and the air thermometer.

The mercurial thermometer consists of a small glass tube A C of uniform bore, to the end of which a bulb B is blown; this bulb and a small portion of the stem are filled with quicksilver, and the open end of the tube is hermetically sealed.

Under ordinary circumstances, water always boils and freezes at the same temperature: this gives us the means of fixing a true scale of comparison for all thermometers. In our country the freezing temperature of water is called 32°, and its boiling temperature 212°, so that between these two points of the scale we have 180 equal divisions or degrees, each equal portion being the amount of expansion due to 1° of temperature. To graduate the thermometer, therefore, we first plunge the bulb into freezing water, or, what is the same thing, into melting ice, and place a mark of 32° at A, opposite to the point at which the mercury stands in the tube; we then plunge the bulb into boiling water, and, in like manner, place a mark of 212° at C, opposite to the point at which the mercury now stands in the stem; the distance between these two points A and C is then divided into 180 equal parts, each part being called a degree, and the scale is extended upwards or downwards accordingly.

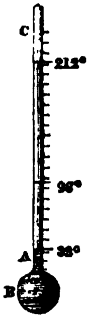


Fig. 90.

The *spirit-of-wine thermometer* is graduated in a similar manner.

The air thermometer. — Fig. 91 represents a common air thermometer. Here the open end of the tube *d*, with its bulb *b* uppermost, is inserted in some colored liquid, which is allowed to rise up a portion of the tube, as to *d*. When heat is applied to the bulb *b*, the air in it expands, and thus depresses the liquid *d* in the tube; from the amount of depression an estimate may be formed of the degree of heat applied to the bulb. These instruments are exceedingly sensitive.

Fig. 91.

The *differential thermometer*, represented in Fig. 92, consists of two glass bulbs *a a* containing atmospheric air, but the lower one is partially filled with a colored fluid which rises in the glass tube to the zero point 0. From this point the degrees on the scale run up and down, as shown in the figure. It will be

understood that when the two bulbs are placed under the same heat, as they usually are when the instrument is not in use, the colored liquid stands at the zero point 0 on the scale; but if the temperature of the upper bulb be raised, then the liquid will sink below this zero point, and,

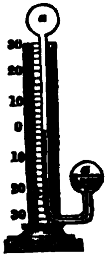


Fig. 92.

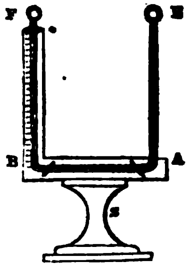


Fig. 93.

on the contrary, if the temperature of the upper bulb be lowered, the liquid will rise above the zero point; hence the instrument has been called the *differential* thermometer, because it measures any minute differences of temperature in the two bulbs.

Fig. 93 represents another form of this instrument.

PROPAGATION OF HEAT.

65. The free caloric, as already stated, in all bodies, tends to a state of equilibrium, or to a state of equality, with respect to its distribution. Heat is propagated by direct radiation, by reflection, and by conduction.

RADIATION OF CALORIC.

66. Radiant caloric, like light, is thrown off from the surfaces of bodies in all directions in right angles.

The intensity of radiant caloric may be measured in the following manner: —

Exp. Place the bulb T (Fig. 94) of an air thermometer near to a hot metal ball M; between them interpose the screen S, through which an aperture O is made.

When the aperture O is brought in a line with the heated ball M and the bulb T of the thermometer, the liquid instantly descends. By

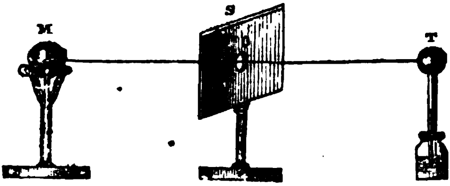


Fig. 94.

placing the bulb of the thermometer at different distances from M, the relative intensities of the radiated heat may be duly ascertained.

In order to show that reflected heat follows the same law as reflected light, place a red hot ball *a* in the focus of the concave tin reflector *n d m*; the rays of caloric will be reflected in the parallel lines *n p m o*

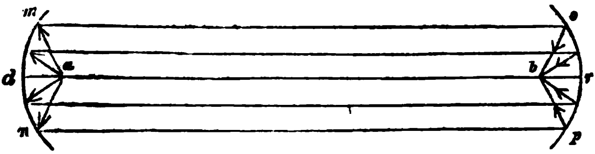


Fig. 95.

&c., and, meeting the second reflector *p r o*, they will be reflected to the focus *b*, and a thermometer placed there will indicate the degree of heat reflected. The surface of these reflectors should have a parabolic form, in order that *all* the parallel rays may meet in the same focus.

If a lump of ice be substituted in the place of the hot ball, the thermometer in the focus *b* will instantly indicate a fall in the temperature. In this case, more caloric radiates from the ball of the thermometer than from the lump of ice; the consequence is, that the ball of the thermometer suffers a diminution in the quantity of its heat.

Exp. Let M and M′ (Fig. 96) be two concave parabolic reflectors, placed at the distance of ten or twelve feet from each other. Place some

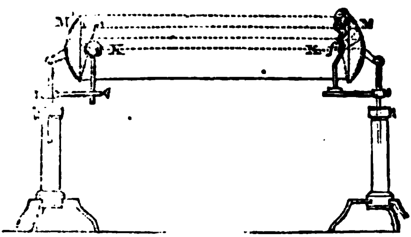


Fig. 96.

phosphorus or gunpowder in the focus f of the reflector M, and a red hot metallic ball in the other focus f'; in a few minutes the phosphorus or gunpowder will be ignited by the heat radiated from the ball and concentrated at the focus f' by the reflectors.

The reflecting power of substances varies not only with the nature of their surfaces, but also with the material of which they consist. Polished metallic surfaces are the best reflectors of heat, and, according to Leslie, brass and silver are the best reflecting substances. Non-metallic bodies have very low reflecting powers; indeed, many of them entirely absorb all the heat which impinges upon them.

A body absorbs that heat which it does not reflect; hence the absorptive power of a body is inversely as its reflective power; and, as a general rule, the power of absorption corresponds with the power of radiation: thus, for example, a surface of lampblack has no reflective power, but it possesses the highest radiating and absorbing power.

Those substances which allow all the rays of heat to pass through them are called *diather'manous;* and those substances which retain all the heat they receive are called *ather'manous.*

Gases, such as the air, are diathermanous; and opaque bodies, such as the metals, are athermanous. The power of a body to transmit heat depends upon its possessing some degree of transparency; but at the same time it is remarkable that the capacity of liquids and solids for transmitting heat is not always in proportion to their transparency or capacity for transmitting light. Rock salt is the most diathermanous of all solids, and alum is the least. Of all liquids water is the least diathermanous.

Leslie's Experiments on the Radiating Powers of different Surfaces.

In these experiments a small canister of tin was employed, one side of which he polished, the second he made rough by scraping, the third he covered with glass, and the fourth he coated with lampblack. He then filled the canister with boiling water, and presented the different sides in succession in

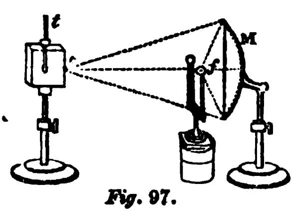


Fig. 97.

front of a concave reflector M, in the focus of which he placed a ball *f*, of a delicate differential thermometer, as shown in Fig. 97. With this apparatus he first verified the law, that, other things being the same, *the amount of radiant heat is proportional to the difference between the temperature of the water and the temperature of the air.* He then showed that the radiation is proportional to the extent of the radiating surface, and inversely as the distance of the radiating surface from the reflector. He further showed that the polished face of the canister radiated the least, and that covered with lampblack radiated the most; and so on to the radiating powers of the other surface.

CONDUCTION OF HEAT.

67. It has already been shown (see page 180) that bodies differ very much in their powers of conducting heat. The following simple experiment shows, in a marked manner, the difference in the conducting powers of rods of different substances.

Exp. Take two equal rods, (say of iron and glass;) tie them together at one end with a piece of fine wire, and attach a ball of wax at their other extremities, *b* and *d*, as shown in Fig. 98; apply the flame of a spirit lamp to the part *a c*, where the rods are connected; then the wax on the iron rod will be completely melted, while that on the glass rod will remain unchanged; thereby showing that iron is a much better conductor of heat than glass.

Fig. 98.

The propagation of heat in liquids varies according to the part at which the heat is applied. When the heat is applied at the surface, the conduction goes on very slowly; in this case the liquid conducts heat in the usual manner: but when the heat is applied to the lower portion of the liquid, the heated particles, being specifically lighter than the cold particles, rise successively to the surface, while the cooler particles at the surface descend; and thus this constant current diffuses the heat equally throughout the whole mass. But this transmission of heat takes place independently of the ordinary principle of conduction; it is, in fact, an operation of *conveyance*, not of conduction from particle to particle.

The following experiments sufficiently establish the truth of these laws: —

Exp. 1. Partly fill a flask with water, and throw some powdered amber (or any substance having nearly the same specific gravity as water) into it; heat the water by a spirit lamp; the currents in the fluid will be apparent from the ascent of the particles of amber up the middle of the water, and from their descent at the sides of the vessel, as shown in Fig. 99.

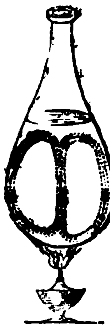


Fig. 99.

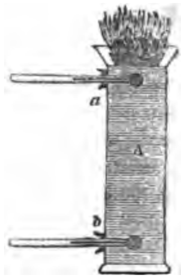


Fig. 100.

Exp. 2. A (in Fig. 100) represents a tin vessel full of water; *a* and *b* thermometers — one placed near the top of the vessel, the other near the bottom.

Float a metal cup *c*, filled with spirits of wine, on the surface of the water; set fire to the spirit, and the heat produced will very soon be shown by the thermometer *a*, but the thermometer *b* will remain for a long time without showing any indications of heat.

Remove the cup *c*, and place the vessel on a lump of ice; the lower thermometer *b* will now in a short time indicate a reduction of temperature, while the upper thermometer *a* will remain unchanged.

These experiments show that water is a bad conductor of heat.

Place the vessel on a hot plate or brick; the whole of the water will become rapidly heated, and both thermometers will indicate the same or nearly the same amount of heat.

Place a piece of ice upon the surface of the water; both thermometers will speedily indicate a decrease of temperature. The particles of the water, as they cool, become heavier, and descend to the bottom, while the lighter particles at the bottom rise to the top, and so on.

But the water at the bottom cannot be cooled in this way below 39°,

for *water attains its maximum density before it reaches the freezing point, that is, at a temperature of* 39°.

Heat of the Ocean.

68. In the temperate and torrid zones the temperature of the ocean, generally speaking, diminishes as the depth below the surface increases; but the reverse of this takes place in the frigid zones, for when the water at the surface is less than 32°, the lower portions cannot have a lower temperature than 39°, for this is the temperature corresponding to the greatest specific gravity of water. Hence it is that ice is always formed upon the surface of the water, and not at the bottom. Hence fishes are enabled to live in our northern seas.

If the ordinary law of density, as depending upon temperature, had existed in this case, the whole of the northern seas would have been converted into one solid mass of ice.

Heat of the Atmosphere.

69. Aeriform bodies resemble liquids in their laws of conduction and conveyance of heat. Still air is the worst conductor of heat, but by the rapid ascent and descent of its particles, it distributes heat even more rapidly than water. The various motions in the atmosphere, noticed in Pneumatics, depend upon this property.

Queries.

70. The student will now be able to answer the following queries: —

1. Whether will water boil sooner in earthen ware vessels or in tin ones?
2. What is the use of having double windows in a house?
3. Why do brass cannon become sooner hot than iron ones?
4. If we touch a piece of wood and a piece of metal, both at a temperature higher than our body, the metal feels hotter than the wood. Why?

5. Thatched roofs are cooler in summer and warmer in winter than slate roofs. Why?

6. What is the use of making boilers and saucepans with wide bottoms?

7. Why are woollen shirts warmer than linen ones?

8. What part of a crowded church is the coolest?

9. Snow is a bad conductor of heat. What is the utility of this property?

10. Why does a man blow his hands to make them warm, and his soup to make it cool?

11. Why are people liable to catch cold when they get their clothes damp?

12. Why should an ink bottle have a small mouth?

Rate of Conduction in Bodies.

71. The rate at which heat is conducted depends upon the difference of temperature between the bodies, or parts of a body, that are in contact. This will be manifest from the following experiment: —

Exp. Plunge a thermometer into hot water; at first the ascent of the mercury in the tube is very rapid, but as the temperature of the mercury in the bulb approaches the temperature of the water, the ascent of the mercury goes on more and more slowly.

Heat is capable of diffusing itself more or less rapidly through the particles of all bodies.

Capacity of Bodies for Heat. — Specific Heat of Bodies.

72. The amount of free caloric in two different quantities of the *same substance* at the same temperature is proportional to their masses: thus, two pints of hot water will contain twice the quantity of free caloric that one pint of the water at the same temperature does.

If two equal quantities of water, or any other liquid, of different temperatures, be mixed, the heat of the mixture will be the mean of the two temperatures. For example, if a pint of water at 60° be mixed with another pint of water at 80°, the temperature of the mixture will be equal to one half of 140°, or 70°. If their quantities are unequal, their common temperature after mixture will be found by dividing the

sum of the products of their masses into their temperatures by the sum of their masses; thus, if we mix two pints of water at 60° with three pints at 100°, the temperature of the mixture will be equal to $\frac{2 \times 60 + 3 \times 100}{2 + 3} = 84°$. These results may be readily proved by experiment.

Equal weights of *dissimilar substances* — say water and mercury — at the same temperature contain unequal quantities of heat. If we place 1 lb. of water and 1 lb. of mercury on a hot plate, it is obvious that the mercury will attain any given temperature much sooner than the water. The water is said to have a higher *capacity for heat* than the mercury, for it requires a larger quantity of heat to raise it to the same temperature. The quantity of heat required to raise equal weights of bodies 1° is called their *specific heat*. In general, the capacity of bodies for heat decreases with their density; thus mercury has a less capacity for heat than water, because its density is greater; thus the thin air on the tops of mountains has a higher capacity for heat than the dense air in the plains.

Experiment. — Mix 1 lb. of mercury at 66° with 1 lb. of water at 32°; then the common temperature of the mixture will be found to be 33°.

Here the mercury loses 33°, and the water gains 1°; that is to say, the 33° of the mercury only elevates the water 1°, therefore the capacity of water for heat is 33 times that of mercury; or, if we call the capacity or specific heat of water 1, then the capacity or specific heat of mercury will be $\frac{1}{33}$ or .0303.

In this way the specific heat of various bodies may be determined. But the capacity of different substances for heat has been more accurately determined by observing the quantity of ice which the body is capable of thawing. The instrument employed for this purpose has been called a *calorim'eter.*

A change of volume is invariably attended with a change of specific heat. — When the bulk of a body is reduced, its capacity for heat is also reduced, and free caloric is evolved. When the bulk of a body is increased, its capacity for heat is also increased, and free caloric is absorbed; and hence the change is followed by a reduction of temperature.

Exp. 1. The sudden condensation of air, in a small tube, having a solid piston fitted to it, will ignite tinder. A little instrument of this kind is sold by philosophical instrument dealers.

Exp. 2. Air forcibly expelled from the mouth feels cold. Here the cold is due to the sudden expansion of the air.

Exp. 3. Iron when hammered becomes hot. Here the hammering brings the particles of the iron nearer to one another.

Exp. 4. Pour water on some quick lime; the water becomes incorporated with the solid substance of the lime, the specific heat of the two substances is reduced, and a powerful heat is therefore evolved. (See also *Experiments* 1, 2, and 3, pages 185–6.)

Heat changes the Form of Bodies.

73. It has been shown (see page 183) that when a body changes its form, either a certain quantity of free heat is absorbed and becomes latent, or a certain quantity of latent heat is evolved and becomes free. Thus, when a body passes from the solid to the liquid state, or from the liquid to the gaseous state, a certain quantity of free caloric is absorbed; and, on the contrary, when a body passes from the gaseous to the liquid state, or from the liquid to the solid state, a certain quantity of latent heat is set free: the former changes produce cold, the latter are attended by the evolution of heat.

The change of solids to liquids is called *fusion* or *melting*. The change of solids or liquids to the vaporous or gaseous state is called *vaporization* when it takes place with boiling or *ebullition*, but when the change takes place at ordinary temperatures of the air, it is called *evaporation*.

Exp. 1. Heat a small piece of brimstone in a test tube; the brimstone first melts, and then rises in the form of vapor; these vapors condense on the upper portion of the tube.

Exp. 2. Heat a very small piece of iodine in a flask; the flask becomes filled with the beautiful violet-colored vapor of iodine.

Exp. 3. Boil some water in a retort, and receive the condensed steam in another glass vessel. (See Fig. 101.) This is called distilled water, and the operation is called distillation.

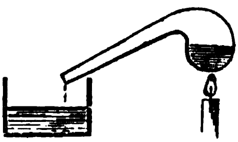


Fig. 101.

Exp. 4. Apply the heat in the last experiment so as to cause the steam to blow out of the nozzle of the retort; now quickly invert the retort with its nozzle in the water; a sudden and violent condensation of all the steam in the retort will take place, and the cool water will rush into the retort and will completely fill it.

The Latent Heat of Steam.

74. Fig. 102 represents an apparatus for generating and condensing steam, so as to enable us to ascertain the amount of its latent heat. A is a copper boiler; *a b* the steam pipe leading into a vessel *b* containing water; the steam, as it enters the cold water, is instantly condensed, and imparts its latent heat to the water in the vessel until it reaches the boiling point. Let 5½ oz. of water at 32° be placed in the vessel *b*, and let the processes of condensation go on until the water is raised to the temperature of 212°; then it will be found that there are 6½ oz. of water in the vessel *b*; that is to say, the condensation of 1 oz. of steam has raised 5½ oz. of water from the temperature of 32° to that of 212°. Hence it follows that the latent heat of a given portion of steam is capable of raising 5½ times its weight of water 180°, and therefore it will raise an equal weight of water 5½ times 180°, or 990°, or, in round numbers, 1000°. This number, therefore, represents the latent heat of steam.

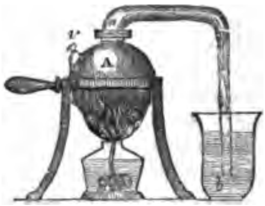


Fig. 102.

Expansive Force of Steam.

75. When steam is generated in a close vessel, like the boiler of a steam engine, as the temperature of the water is raised, so the density and pressure of the steam is raised accordingly.

Fig. 103 represents an apparatus for ascertaining the law of relation between the temperature and pressure of steam. B is the boiler partly filled with water; L the heat applied to it; A B a barometer tube, open at both ends, dipping into a portion of mercury at the lower part of the boiler; T a thermometer with its bulb inserted in the steam; C a stop cock, which may be closed or opened at pleasure. Now, when the temperature of the steam is raised above the boiling point, (212°,) the mercury rises in the barometer tube A, and the height of the mercury and

the temperature, as indicated by the thermometer, being observed at the same instant, gives us the means of determining the relation between the pressure and temperature of the steam. When the steam issues from the cock C, the mercury in the tube A B is at the same level as the mercury in the boiler, and then the pressure of the steam is the same as that of the atmosphere, which we estimate at a column of 30 inches of mercury; when the stop cock is closed, and the mercury in the tube A B rises, we must add this column of mercury to the 30 inches for the total column, balancing the pressure of the steam in the boiler. Thus, for example, when the temperature is 232°, the mercury in the tube A will stand at the height of 15 inches above the level of the mercury in the boiler, that is to say, the pressure of the steam in the boiler will be measured by a column of mercury equal to 45 inches, or, in other words, the pressure of the steam at 232° will be 1½ times the pressure of the atmosphere, or equal to about 22½ lbs. per square inch. Experimental tables have been constructed, giving the relation of the temperature and pressure of steam.

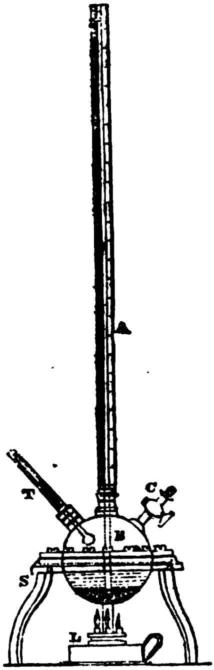


Fig. 103.

Various simple pieces of apparatus have been constructed to illustrate the expansive force of steam generated under high pressure.

Fig. 104 shows how the expansive force of a jet of steam issuing from the pipe *a b*, and impinging upon the vanes of a wheel W, is capable of imparting a rotating motion to the wheel.

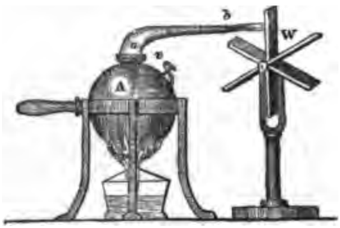


Fig. 104.

Fig. 105.

Fig. 106.

Fig. 105 shows how the reaction of the steam, issuing from the nozzles *b b b b*, gives a rotatory motion to the globe A.

Fig. 106 shows how a jet of steam, projected on the flame *b*, may be used as a blast for a blowpipe.

Dalton used the Torricellian tube to estimate the expansive force of steam, at temperatures below the boiling point of water. He filled the Torricellian tube *b d* with mercury, and inverted it in the mercury contained in the vessel A; he then introduced into the tube a small quantity of the liquid whose vapor he wished to examine. This liquid rises to the top of the mercury, and occupies a portion of the vacuum space; it there gives off its vapor, which causes the mercury to sink in the tube, and to stand at a height *m* corresponding to the elasticity of this vapor, which is dependent upon its heat. This reduction of the column of mercury gives the column of mercury due to the pressure of the vapor at the particular temperature. In order to vary the temperature at pleasure, he surrounded the upper part of the Torricellian tube with a wide glass tube *c*, and filled it with water, in which he placed a thermometer. He then heated this water, which caused the mercury to descend in the tube, and occupy a position corresponding to the elasticity of the vapor in the upper portion: by noting the temperature and the height of the mercury at the same instant, he was enabled to give the relation between the temperature of the vapor and its elastic pressure.

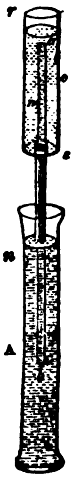


Fig. 107. *Fig.* 108.

EVAPORATION.

76. The leading laws and effects of evaporation have been explained. The following experiments and expositions are intended to place the subject in a more prominent and scientific point of light.

Exp. 1. *Water frozen by evaporation.*—*a a* is a glass vessel containing strong sulphuric acid, over which is placed a tripod stand, supporting a porous cup *c c* of earthen ware, filled with cold water: the whole is placed under a glass bell *d d*, on the plate of a *good* air pump. When the air is exhausted from the receiver, the water in the cup becomes gradually converted into ice. Here the exhaustion of the air causes the evaporation of the water to go on with increased rapidity; at the same time, the sulphuric acid absorbs this vapor as it is being formed: the rapid evaporation from the surface of the water produces a cold sufficient to freeze it.

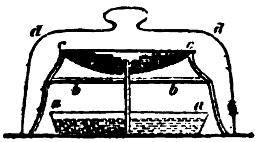


Fig. 109.

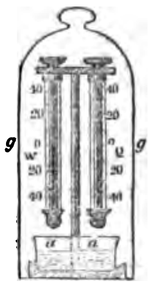


Fig. 110.

Exp. 2. *Mercury frozen by evaporation.*—Q is a mercurial thermometer, and W a spirit-of-wine one, fixed side by side; *a a* is a glass vessel placed about three inches below the balls of the thermometers, which are wrapped with cotton, saturated with rectified sulphuric ether; the whole is placed under a receiver *g g*, on the plate of an air pump. When the air is exhausted from the receiver, the cold produced by the rapid evaporation of the ether will cause the mercury to become solid; the temperature at which this takes place, as indicated by the spirit-of-wine thermometer, is about 40° below zero.

The *cryophorus* was invented by Wollaston, for freezing water by its own evaporation: it consists of a glass tube A B (see Fig. 111) terminated with two bulbs C and D, on short branches bent at right angles to it. A portion of water is introduced through a little tube O at the bottom of the bulb D. This water is then boiled in C until all the air is blown out, and the whole interior space is filled with steam; the tube O is then closed by melting its fine extremity in the flame of a blowpipe. When the instrument has become cool, the enclosed water is then sur-

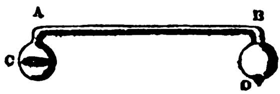


Fig. 111.

rounded by its own vapor raised in a vacuum. Having described the instrument, let us now see how it is used. Plunge the empty bulb D into a freezing mixture of snow and salt, and the water in the other bulb will speedily be turned into ice. Here the cold produced by the freezing mixture is constantly condensing the aqueous vapor in the bulb D; and as there is no air in the tube, more and more vapor is continually rising from the water in the other bulb, and this goes on until so much heat is abstracted from the water by the evaporation that it freezes.

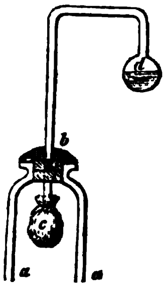


Fig. 112.

Fig. 112 represents another form of this instrument, where sulphuric ether is substituted for the freezing mixture. *d* is the bulb containing the water which is to be frozen; *c* the empty bulb wrapped round with some cotton moistened with ether; to hasten the evaporation of the ether, air is blown from a pair of bellows upon the bulb *c*. The experiment may be performed more quickly by enclosing *c* in the exhausted receiver *a b a* of an air pump.

Moisture in the Air.—Hygrometers.

77. The instruments used to measure the moisture of the air are called hygrometers.

Fig. 113.

Saussure's hair hygrometer.—The mode of action of this instrument depends on the fact, that substances like hair readily imbibe moisture from a damp atmosphere, and, on doing so, swell out in thickness, but contract in length. This instrument is represented in Fig. 113. A B is a human hair, about one foot long, (freed from all grease by boiling it in a weak solution of soda or potassa;) one end of it is fastened to a hook at B, and the other is passed over a fixed pulley P, and is strained tight by means of a small weight W. The contraction and expansion of this hair give motion to an index pointer C, which moves over the face of the graduated arc *a*. The two extreme points of this scale are, where the index pointer stands in a perfectly dry atmosphere, and where it stands in an atmosphere saturated with moisture. The former point is marked 0, or zero, and the latter is usually marked 100; and the intervening arc is divided into 100 equal parts, each part being called a degree. The zero point is obtained by enclosing the instrument in a glass bell, from which the aqueous vapor is withdrawn by means of dry chloride of calcium, or strong sulphuric acid: the point

of greatest humidity is determined by placing the instrument in a glass bell standing over water. It must be observed, however, that the degrees of humidity shown by this instrument are not *exactly* in proportion to the humidity existing in the air: indeed, it is exceedingly difficult to make a perfect hygrometrical instrument.

The experiment explained at page 184 gives a simple and tolerably accurate method of determining *the dew point* of the atmosphere at any time.

The mercurial hygrometer. — A good instrument of this kind is represented in Fig. 114. A and B are two ordinary mercurial thermometers placed by the side of each other; the bulb A is surrounded with muslin, which is kept in a damp state by means of a cotton thread attached to it, the other end of the thread being placed in a cup W of distilled water; the other bulb B is kept dry. Now, as the water evaporates from the muslin, the mercury in the thermometer A falls; and the drier the surrounding air at the time, the more rapid is the descent of the mercury; and when the air about the bulb A becomes saturated with moisture, the mercury in the tube becomes stationary, and the point at which it stands will be the dew point of the air at that time. The greater the difference between the two thermometers, the greater will be the dryness of the air. When the damp thermometer A indicates no decrease of temperature, then the surrounding air at that moment will be saturated with moisture.

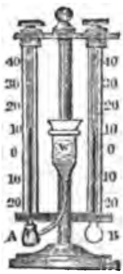


Fig. 114.

Certain Meteorological Phenomena. — Dew. — Clouds. — Rain. — Snow.

78. When the surface of the earth has become heated, it imparts its heat by radiation to the surrounding air; during the day, therefore, the lower strata of the atmosphere are warmer than the upper But a change takes place after sunset. The surface of the earth still goes on radiating its heat; but it now receives no heat in exchange, so that its temperature at length falls below that of the air. Now, the air immediately in contact with the cold surface of the earth becomes cooled down, and, if the temperature falls to the dew point of the air, then the vapors in it are condensed on the surface of the plants, or the soil, in the form of small drops or dew, just

in the same way as the cold tumbler becomes covered with moisture in a warm room. If the temperature of the earth's surface sinks to the freezing point, the moisture is deposited in the form of *hoar frost.*

The surface of the earth radiates most heat when the sky is clear and serene; but it is especially obstructed by clouds, which, like a screen, radiate back to the earth the heat which they receive from it. Hence it is, that *clear, cloudless nights are most favorable for the formation of dew.*

To arrest the radiation of heat from the earth, the gardener covers his tender plants with matting or straw.

Winds and mountains are the great causes of rain. When a warm air, nearly saturated with moisture, is mixed with cold air, moisture is always precipitated, and becomes visible to us, assuming either the form of clouds or rain.

Suppose a warm air to be driven by a wind towards a mountain M; when the air strikes the sloping side of the mountain, it rises, on the principle of the resolution of motion, and it is carried over the mountain

Fig. 115.

top; by this means the air is carried from a warm to a cold region; its moisture, therefore, is precipitated, and assumes either the form of clouds or rain, or, it may be, when the cold is very great, that of snow or hail. Hence rivers take their rise in mountain ranges.

Mountains also frequently attract the clouds towards them, and thus cause rain to fall.

The two great processes of *evaporation* and *condensation* are the means whereby the vegetation of the earth is contin-

ually supplied with moisture from the great reservoir of waters — the ocean — which covers the larger portion of the globe.

Philosophers have found it difficult to account for the suspension of the particles of moisture in the clouds. It is generally believed that the moisture in the clouds assumes the form of vesicles of watery vapor, or little buoyant air bubbles, which, being in the same electrical state as the stratum of air immediately below them, not only repel one another, but are, at the same time, repelled by the air beneath; and thus they are supported in opposition to the force of gravity. *Query.* May not these vesicles be supported in the same way as a little sewing needle is supported upon the surface of water?

ELECTRICITY.

PRELIMINARY VIEWS AND EXPERIMENTS.

1. WHAT is electricity? It is a subtile fluid which pervades all nature, and which becomes known to us by its peculiar properties, or by the way in which it affects our senses. Lightning is electricity; in the thunder storm nature generates the electric fluid on a mighty scale. Electricity is most easily generated by friction; or, to speak more definitely, it is rendered apparent to our senses when certain bodies are rubbed against each other. Electricity appears to exist in all bodies, in a latent or hidden state; but friction and other causes disturb this state of quiescence or inactivity. There are various means of generating electricity besides friction,—for instance, heat, chemical action, or pressure will generate it,—but we purpose first to show its various properties when it is generated by friction.

EASY COURSE OF EXPERIMENTS, WITH SIMPLE PRINCIPLES DERIVED FROM THEM.

2. The following electrical experiments may all be performed by any intelligent person, with no other apparatus than what may be obtained in any ordinary dwelling house. All the experiments here described have been repeatedly performed by the author with invariable success. Many of them, he believes, are new and simple, and highly calculated to interest young persons, from the very fact that they have it in their power to repeat the experiments at any time they may wish to do so.

Bodies which are electrified, or which contain free electricity, attract and repel light substances; and when the electricity is generated in a sufficient quantity, luminous sparks,

accompanied by a sharp, cracking noise, pass from the electrified body to any body which is not electrified.

These fundamental facts of electricity are illustrated by the following experiments: —

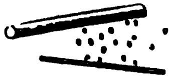


Fig. 1.

Exp. 1. Rub a stick of stealing wax, or a dry glass tube, with a warm piece of flannel or silk: electricity is generated. Hold the excited stick of sealing wax over some cuttings of light paper, or any other light substances: the bits of paper will be attracted by the sealing wax, and will sometimes fly and dance up and down.

Bring the excited sealing wax before your eyes: a sensation is felt as if spiders' webs were drawn across your face.

Bring the sealing wax under your nose: you feel a faint smell like phosphorus.

Suspend a feather or a little cork ball by a silk thread, as shown in Fig. 2; bring the excited sealing wax near the little ball: it is first attracted, and then it is repelled.

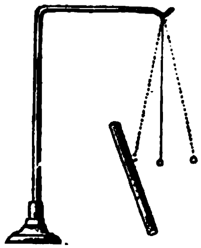


Fig. 2.

Those substances which readily yield electricity by friction have been called *electrics*. But it has recently been found that all substances possess this property in a greater or less degree.

Exp. 2. Suspend two feathers (or two light cork balls) by silk threads, as shown in Fig. 3; bring the excited sealing wax near the feathers: they are first attracted to the sealing wax, and then they are repelled from it; and they will finally be found to diverge or fly from each other, as shown in the figure.

Here it will be observed that the electrified body first attracts the feathers; and then, when they become electrified, in the same way as the sealing wax, they are repelled by it, and mutually repel each other.

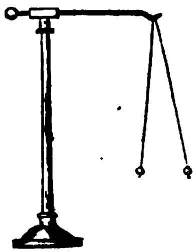


Fig. 3.

Exp. 3. Bring the excited stick of stealing wax near a light, downy feather, floating in the air: the feather will first be attracted to the sealing wax, and then repelled from it. As the sealing wax is moved

towards the feather, it will continue to fly away. In this way the feather may be driven about the room. If the feather should touch any body not electrified, it will fly back to the sealing wax again. Or if an excited glass tube be brought near the feather, it will be attracted.

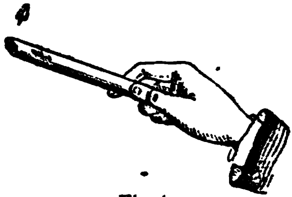


Fig. 4.

Here the excited sealing wax first attracts the feather; and then, when the feather becomes electrified in the same way as the sealing wax, it is repelled.

Exp. 4. Take up a black cat, which has been lying before the fire; hold it by the throat with one hand, and with the other hand rub it smartly along the back: electricity will be generated; the hair will become so excited and charged with the electrical fluid that a faint shock may sometimes be felt, and a succession of sparks may be seen, if the experiment is performed in the dark.

Exp. 5. Take two strips of brown paper, about 9 inches long and 2 inches wide; *warm* them, and hold them by the finger and thumb of the left hand; rub them briskly, by inserting the fore finger of the right hand between them, and then drawing it sharply from end to end: the strips of paper will be powerfully electrified, and will diverge from each other, as shown in Fig. 5. They repel each other because they are electrified in the same way.

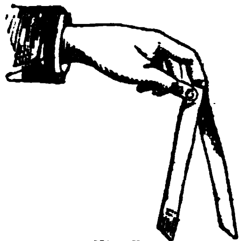


Fig. 5.

Bring the hand between them when thus repelled, and they will both be attracted by the hand.

Exp. 6. Lay the two strips of brown paper, the one over the other, on a smooth table; rub them with the hand, or, what is still better, draw the edge of an ivory rule or scale over them for a few times; lift them from the table, and then separate them from each other: they will attract each other very powerfully.

In the last experiment, they repelled each other because they were electrified in the same way; but here they attract each other, because they are electrified in different ways. It will be afterwards shown that, whilst the bottom piece of paper is *positively* electrified, the top piece is *negatively* electrified.

The two foregoing experiments may be performed with silk ribbons, or with strips of thin sheet gutta percha.

In the place of the hand, an old fur cuff, or a hare's skin, or Indian

rubber, or a piece of warm flannel, or an ivory scale, may be employed as the rubber.

Exp. 7. Take two pieces of lump sugar, and rub them together in the dark: they will appear covered with a beautiful lambent flame of electric light.

Exp. 8. Take a piece of stout common brown paper (or a sheet of thin gutta percha) about a foot long and nine inches broad; hold it before the fire until it is quite hot,* lay it upon the table, and rub it briskly for a few times with the palm of the hand: the paper will become powerfully electrified.

(1.) Lift the paper by one corner from the table, and it will be found that some force is required to separate the paper from the table.

(2.) Hold the electrified paper as in Fig. 6; bring the extended

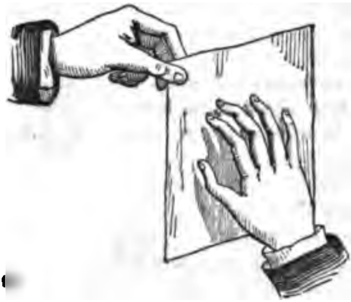


Fig. 6.

fingers of the right hand near to the surface of the paper: it will be attracted to the hand, and electric sparks, giving a snapping sound, will pass from it to the fingers.

(3.) Hold some feathers, suspended by silk thread, near to the excited paper, as shown in Fig. 7; the feathers will be powerfully attracted.

(4.) Hold the excited paper, or the excited sheet of gutta percha, as the case may be, over the head of a person having dry hair, as shown in Fig. 8; the hair will be powerfully attracted by the paper, and each particular hair will appear as if standing on end.

(5.) Hold the excited paper over the face; a sensation like that produced by cobwebs spread over the face will immediately be felt.

(6.) Perform experiments 1, 2, and 3 with the electrified paper.

Exp. 9. Take two pieces of stout brown paper, of the same size as that described in Exp. 8; after heating them, lay the one upon the other,

* Gutta percha should never be heated.

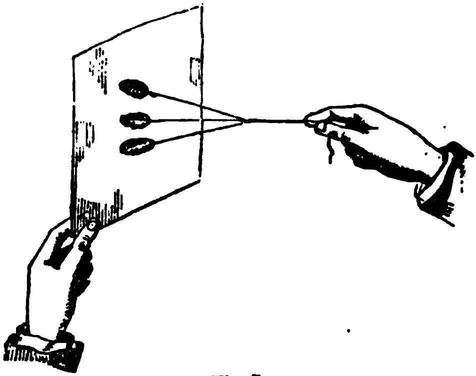


Fig. 7.

and rub the upper surface with the palm of the hand; tear the two sheets of paper from the table; they will adhere firmly together. A crackling sound will be heard, upon separating them from each other; and upon

Fig. 8.

being brought near to each other, they will mutually attract each other, and will again adhere to each other. If they are separated from each other in the dark, an electric flash will be distinctly observed.

Exp. 10. Hold the excited paper near to the wall of the room: the paper will fly to the wall, and will remain there some minutes without falling.

Exp. 11. *To obtain a series of electric sparks.*—Take a small tea tray, and place it upon a dry tumbler glass, as shown in Fig. 9; place the excited sheet of paper or gutta percha, described in Exp. 8 or 9,

upon the tea tray; bring the knuckle near to the tea tray, and an electric spark will be received; quickly withdraw the paper, and again apply the knuckle, and another spark will be received; replace the paper, and then apply the knuckle, and another spark will be perceived; and so on for at least a dozen times.

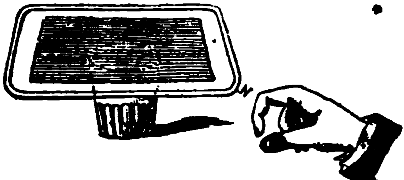


Fig. 9.

Exp. 12. Take a small splinter of wood, about 9 inches long; fix corks to its extremities; suspend it from its middle by a silk thread; bring the excited stick of sealing wax, or brown paper, near to one of the corks: it will be attracted, and, by moving the electrified body in a circle, the cork, being constantly attracted, will appear to revolve on the thread as an axis.

Exp. 13. Make a notch in the middle of the rod, described in the last experiment, and balance it on the edge of a dinner knife C, as shown in Fig. 10. (The balance of the rod is easily adjusted by pushing either the one cork or the other nearer to the centre of the splinter.) Bring the excited brown paper over the cork A, and it will be attracted; now place the excited brown paper over the cork B, and it will, in its turn, be attracted, and so on; thereby giving an oscillating motion to the rod A B on the edge C. This experiment exhibits electrical attraction in a striking manner, being conducted on a large scale.

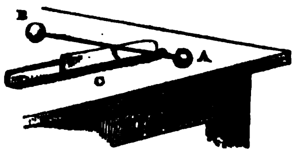


Fig. 10.

Exp. 14. *To make two forks revolve by electrical attraction.* — Stick two small forks A and B into a cork C, as shown in Fig. 11; stick a sewing needle, with its point outwards, into the cork; poise the whole on the point of the needle standing on the top of a wine glass G; bring the excited sealing wax or brown paper near one of the forks, and make it revolve, as in Exp. 12.

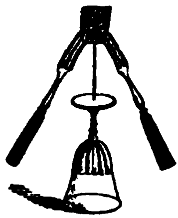


Fig. 11.

Exp. 15. Blow out a lighted candle having a long snuff; bring an excited rod of sealing wax

near to the wick, as shown in Fig. 12; the smoke is attracted by the sealing wax, and sparks of fire appear to fly towards it.

Fig. 12.

Exp. 16. Support a warm pane of glass upon two books, one at each end; place some dry bran, or cuttings of fine paper, or light pith or cork balls, beneath the glass, and briskly rub the upper side with a warm piece of flannel or black silk: the bran will dance up and down with great rapidity.

This experiment was first made by Newton. It was important at the time of its discovery, inasmuch as it showed, what was not known before, that *an electrical body became electrified on the side contrary to that which was excited.*

CONDUCTORS AND NON-CONDUCTORS OF ELECTRICITY. INSULATION.

3. The metal tea tray of Exp. 11 was placed upon a glass tumbler, because glass is a *non-conductor* of electricity; and, in like manner, the feathers of Exp. 2 were suspended by silk threads, because dry silk is a non-conductor of electricity. If the feathers had been suspended by a metallic wire, in the place of silk, they would not have diverged from each other in the manner described, for metals conduct the electric fluid.

The electric fluid does not diffuse itself over the surface of a non-conductor, but remains confined strictly to that portion of the surface which first received it; thus, when one end of a stick of sealing wax is rubbed, that extremity becomes highly electrified, whilst the other extremity remains in its natural state. On the contrary, conductors freely convey the electric fluid from one part of their surface to another; and thus the electric fluid instantaneously diffuses itself uniformly over the whole surface of the conductor, just as water would spread itself over a level surface. All metallic bodies are excellent conductors; and water, wood, &c., as well as all substances in a damp state, readily conduct electricity. The earth is the great reservoir and conductor of electricity. When any electrified body is suspended from or supported by a non-con-

ductor, the body is said to be *insulated.* All non-conductors, therefore, are called *insulators.* Glass rods, silk threads, sealing wax, and fine threads of sealing wax, are the insulators most commonly used in performing electrical experiments. All these substances become conductors when they are in a damp state; hence the necessity of having all our insulators perfectly dry and warm. Sealing wax is the best of all insulators, because it does not readily become covered with moisture. For conducting delicate experiments, there is no insulator to be compared with a fine thread of sealing wax or gum lac.

Bodies differ very much, as well in their conducting as in their insulating powers. Of all bodies metals are the best conductors, and resinous bodies are the best insulators or non-conductors. The bodies in the following list possess these powers, in the order in which they are named.

Classification of Conductors according to their conducting power.

1. All the metals.
2. Charcoal.
3. Plumbago.
4. Acids.
5. Metallic ores.
6. Animal fluids.
7. Water, and all damp substances.
8. Ice above 13° Fahrenheit.
9. Snow.
10. Living animals and vegetables.
11. Flame, smoke, and steam.
12. Soluble salts.
13. Rarefied air.
14. Vapors of ether and alcohol.
15. Damp earth and stones.
16. Powdered glass.
17. Flowers of sulphur.

Classification of Insulators according to their insulating power.

1. Gum lac, gutta percha.
2. Amber.
3. Resins, sulphur, wax, jet.
4. Glass, and all vitrifactions.
5. Mica.
6. Diamond, transparent gems.
7. Raw silk, bleached silk, dyed silk.
8. Wool, hair, feathers.
9. Dry paper.
10. Parchment, leather.
11. Atmospheric air, when dry.
12. All dry gases.
13. Baked wood.
14. Porcelain and dry marble.
15. Camphor, Indian rubber.
16. Lycopodium.
17. Dry chalk, lime, phosphorus.
18. Ice below 13° Fahrenheit.
19. Many dry, transparent crystals.
20. Oils, dry oxides of metals.

Conducting substances were, at one time, called *non-electrics*, and non-conductors were called *electrics*; but the distinction is not founded on fact, because conducting substances, when insulated, will yield electricity by friction; and besides, the capacity of a substance for yielding electricity by friction does not seem to depend upon the insulating or non-conducting power of the substance.

The atmosphere manifestly belongs to the class of non-conductors; if this had not been the case, no electrified body could have retained its electricity for any length of time. When air becomes rarefied, it loses its insulating property; thus, an electrified body soon loses its electricity when placed in the exhausted receiver of an air pump. The electric fluid spreads itself in a thin coating over the surface of the electrified body, and it is prevented from escaping by the pressure or tension of the surrounding air; when this pressure is reduced beyond a certain degree, the electricity escapes from the surface.

ELECTROSCOPES.

4. Electroscopes are instruments used for detecting the presence of electricity in bodies; such as the suspended pith balls represented in Fig. 3.

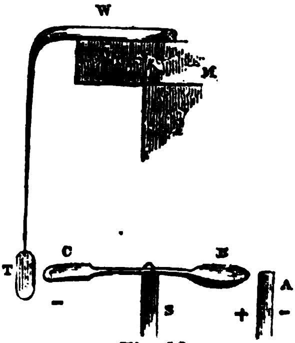


Fig. 13.

By means of an electroscope we can readily show that there are two kinds of electricity; the one being called *positive* electricity, and the other *negative* electricity. There are various electroscopes, but the following one is easily made, and is quite delicate enough for all ordinary electrical experiments.

To make a simple electroscope.—Take a narrow strip of tin foil; melt the end of a stick of sealing wax; attach it to one end of the tin foil, and draw the wax out into a fine thread, as shown in Fig. 13, where T represents the tin foil, and W the sealing wax; place the stick of sealing wax on the mantel shelf M, and you will have constructed a very useful elec-

troscope, with which the following demonstrative experiments may be successfully performed.

5. There are two kinds of electricity.

Make two simple electroscopes; excite a stick of sealing wax, and also a dry glass tube; the electricity of the sealing wax, which is said to be *negative*, will be different from the electricity of the glass, which is said to be *positive*, as may be shown by the following experiments:—

Exp. 1. Touch the strips of tin foil with the excited glass tube, bring them near to each other, and they will fly from each other, as shown in No. 1, Fig. 14. Here the bodies repel each other, because they are electrified in the same way; that is to say, they are *both* in a state of *positive* or *plus*, +, electricity.

No. 1. No. 2. No. 3.

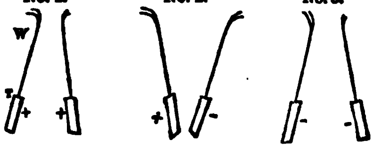


Fig. 14.

Exp. 2. Perform the same experiment with the excited sealing wax, and the strips of tin foil will repel each other, as shown in No. 3, Fig. 14. Here the bodies are *both* in a state of *negative* or *minus*, —, electricity.

Exp. 3. Touch one of the strips of tin foil with the excited glass tube, and touch the other strip with the excited stick of sealing wax; bring the strips thus electrified near each other; they will be powerfully attracted to each other, as shown in No. 2, Fig. 14, thereby proving that the electricity generated by the friction of glass is different from the electricity generated by the friction of sealing wax.

These experiments may be readily performed with one electroscope in the following manner:—

Exp. 4. Bring the excited stick of sealing wax near the strip of tin foil; it will be first attracted, and then it will remain permanently repelled. Any other excited stick of sealing wax, or any excited resinous substance, will repel the electrified strip. Now bring an excited glass tube near to the electrified tin foil; it will be instantly attracted.

From these experiments we derive the following law, relative to the two kinds of electricity:—

Bodies electrified in the same way repel one another; bodies electrified in different ways attract one another. Or we may express this law by simply stating, that like electricities repel, and unlike attract.

By this law of electrical polarity we may easily ascertain to which kind of electricity any excited body belongs.

Exp. 1. Suppose we wish to know whether the excited brown paper of Exp. 5, p. 208, is positive or negative.

Touch the strip of tin foil T, (Fig. 13,) with an excited stick of sealing wax, and the tin foil will be negatively electrified: now bring the excited brown paper near to the strip of tin foil; it is repelled; therefore the paper is electrified in the same manner as the sealing wax; that is, it is in a state of negative electricity.

Or we may proceed as follows: Touch the tin foil of the electroscope with an excited glass tube; bring the excited paper near to the tin foil; it is instantly attracted, thereby showing that the electricity of the excited paper is unlike the electricity of the excited glass; that is, the electricity of the paper is negative.

Exp. 2. Perform the same experiment with excited sulphur. It will be found to possess negative electricity.

Exp. 3. Rub a glass tube with a black cat's skin; test the electricity of the glass; it will be found to be negative, thereby showing that the same substance may be positively or negatively electrified, according to the nature of the rubber.

Exp. 4. Test the electricities of the two sheets of brown paper of Exp. 6, p. 208; the upper sheet will be negative, while the bottom sheet will be positive.

After separating the sheets of brown paper, place them on opposite sides of the tin foil; it will fly with great rapidity backwards and forwards from the one sheet of paper to the other.

Exp. 5. Hold an excited stick of sealing wax and an excited glass rod near to the tin foil of the electroscope; the tin foil will fly backwards and forwards from the one to the other. Perform the same experiment with the flying feather of Exp. 3, p. 207.

6. Electricity remains on the surface of a non-conductor when it is electrified; that is to say, the electrified fluid does not pass from one part of the surface to another part.

Experiment. Excite the *whole* surface of a piece of sealing wax with dry silk; run the fore finger down *one side* of the excited sealing wax; touch the tin foil of the electroscope with that side of the sealing wax

from which the electricity has not been taken away, then the tin foil will be repelled; turn the sealing wax round, then the tin foil will no longer be repelled. Here it will be seen that the electricity does not spread itself from one side of the sealing wax to the other side.

7. The electricity of the rubber is different from the electricity of the body which is rubbed.

Exp. 1. Lay a piece of dry silk upon the table, and rub it with a stick of sealing wax; lift up the excited silk by one corner, and touch the tin foil of the electroscope with it, then the tin foil will be charged with positive electricity; bring the excited sealing wax near to the tin foil, and it will be powerfully attracted, thereby showing that while the sealing wax is in a *negative* state of electricity, the silk is in a *positive* state.

Exp. 2. Tie a piece of silk or flannel to the end of a stick of sealing wax; rub a warm plate of glass with the insulated silk, taking care to hold the rubber by the insulating handle; test the electricity of the rubber and the excited glass by means of the electroscope, and it will be found that the silk rubber is negative, while the glass is positive.

Exp. 3. Rub a sheet of brown paper in the same manner. In this case the silk rubber will be positive, and the sheet of paper negative.

THEORIES OF ELECTRICITY.

8. These experiments led some philosophers to consider that there was only one electric fluid, and that it existed in the glass, which was rubbed, in excess, or in a plus state, while it existed in the rubber in deficiency, or in a minus state. According to this theory, the friction deprives the rubber of a portion of its natural electricity, and transmits it to the glass, which thereby receives more than its natural share. This explains the use of the terms *positive* and *negative* electricity. However, as we shall afterwards show, it seems to be more simple for us to regard electricity as consisting of *two fluids*, which mutually attract each other, but, at the same time, each fluid is self-repellent — that is to say, its own particles repel one another. The kind of fluid excited from *glass* and analogous bodies is called *vitreous*; and that from *sealing wax* and the like, *resinous* electricity. The vitreous answers to the *positive*, and the resinous to the *negative*. This theory fully accounts for the electrical attractions

and repulsions; for when the electric fluids in two bodies are unlike, the bodies attract each other, by virtue of the mutual attraction of the two fluids; and, on the contrary, when the electric fluids in the two bodies are like, the bodies repel each other, by virtue of the repellent property of the particles of the same fluid. When equal portions of the two fluids unite, they neutralize each other, and the electricity is then in a neutral or quiescent state, which is the usual state in which electricity exists in bodies. Friction disturbs the equilibrium of the two fluids, by separating the one from the other: the positive fluid attaches itself to the glass, while the negative fluid attaches itself to the rubber. The two fluids, in the natural state of bodies, as it were hold each other in a state of inaction, and electricity is then said to be latent or hidden.

THE SINGLE FLUID THEORY was adopted by Franklin, and after him by most of the English electricians, until very recently, when THE THEORY OF TWO FLUIDS, as above explained, which had been generally adopted on the continent, became more popular amongst us. It must, however, be remembered that the great use of theory in this subject, is to group and classify the vast accumulation of facts which have been brought to light.

CONDUCTION AND INDUCTION.

9. When the electric fluid is transmitted from one body to another through the medium of an insulated conductor, it is said to be conveyed by *conduction;* but when electricity is transmitted from one body to another at some distance from it without receiving a spark, it is said to be by *induction.*

Experiment. Support a tea spoon B C, or any thick metal wire, upon a stick of sealing wax S: this can easily be done by melting the wax, and fixing the spoon to it, as shown in Fig. 13, page 214. The spoon will thus form an insulated conductor.

(1.) Hold the conductor B C by the insulating stick S; bring the extremity C near to the tin foil T of the electroscope; then *touch* the opposite extremity B with an excited stick of sealing wax; the tin foil will be attracted and then repelled. Here the metal B C conducts or

conveys the electricity from the sealing wax A to the tin foil T. This is an example of *conduction;* B C may be any conducting substance.

If the intervening substance B C were glass, or any other non-conductor, the tin foil would not be affected by the contact of A with the extremity B.

(2.) Bring the extremity C of the conductor at the distance of about half an inch from the tin foil; hold the excited stick of sealing wax A at about the same distance from the extremity B; then T will be electrified negatively, which can readily be tested in the usual way. This is an example of electrical *induction.* Take A away, and all signs of electricity will have disappeared from the conductor B C. Here the electricity is conveyed or transmitted from the electrified body to the tin foil through the air, and not by the contact of the conductor with the electrified body. Electrical induction, then, takes place, when electricity is transmitted from one body to another body at some distance from it. The phenomena here exhibited may be explained as follows:—

The negative electricity on A repels the negative electricity in the conductor B C, and attracts its positive electricity; the consequence is, the equilibrium of the two fluids in the conductor is destroyed, the negative fluid flies towards the extremity C, and the positive fluid is attracted towards the extremity B. Hence the tin foil is first attracted towards C, and then repelled from it. And, upon withdrawing the conductor, the tin foil will remain electrified negatively. To prove this, bring an excited stick of sealing wax towards the tin foil T, and it will be repelled.

(3.) Perform the same experiment with an excited glass tube A. In this case the extremity C will be positive, and the tin foil will be charged with positive electricity.

(4.) Repeat Exp. 2, and before taking the electrified sealing wax A away, *first* touch C, and *then* take A away; the conductor will remain positively electrified, which will be shown by its now attracting T. If we touch the extremity B, the conductor will remain electrified negatively.

These effects may be readily explained. When we touch the extremity C, we take away the free negative electricity, and then when A is taken away an excess of positive electricity remains in the conductor. In like manner when we touch the extremity B we take away the free positive electricity, and then when A is taken away the conductor B C remains charged with negative electricity. The truth of these results may be readily verified in the usual way. Observe that the tin foil T will always remain charged with the electricity of the extremity C of the conductor.

Electrical attractions are readily explained upon the principle of

induction: by the action of induction, the body which is attracted is in a different state of electricity from that of the body charged with the electricity.

Tate's simple Gutta Percha Electrophorus.

10. The following apparatus depends upon the principle of induction: —

Take a toy tin plate, costing one penny; heat the bottom of the plate over the flame of a candle, and fix a stick of sealing wax A, as shown in Fig. 15, to its upper surface; lay a sheet of gutta percha (or a sheet of warm brown paper, as the case may be) upon a smooth table, and excite the sheet in the usual way; place the tin plate upon the surface of the gutta percha, and, after touching the plate with the finger, lift it off the gutta percha by means of the insulating handle; apply the knuckle to the tin plate, and a spark of positive electricity will be received. This may be repeated for about a hundred times, without any sensible diminution in the size of the spark.

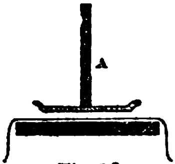


Fig. 15.

Here the friction of the gutta percha generates negative electricity; and therefore, when we touch the plate, we take away a certain portion of negative electricity from it, and consequently, when the plate is raised, it must contain an excess of positive electricity.

In order to give a continuous charge to a conductor, place the insulated tea tray, represented in Fig. 9, directly above the edge of the plate A of the electrophorus, so that when the plate is lifted off the sheet of gutta percha, it shall strike against the edge of the tea tray. In this way a rapid succession of sparks will be transmitted to the tea tray, which will consequently become powerfully charged with positive electricity. An electrical jar, having its knob placed near to the edge of the tea tray, will be soon charged with positive electricity.

11. By means of this electrophorus, the following demonstrative experiments may be readily performed: —

To show that pointed conductors draw off electricity from an electrified

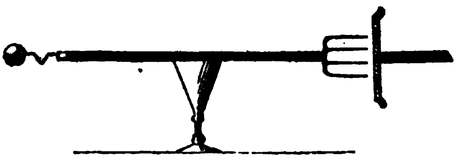


Fig. 16.

body: Place a common toasting fork upon a dry wine glass, as shown in Fig. 16; bring the electrified plate of the electrophorus near to the points of the fork, then a spark may be taken from its opposite extremity.

To exhibit electrical induction and conduction: Place a poker upon a dry wine glass, as shown in Fig. 17; touch one extremity of the poker with the electrified plate of the electrophorus, and a spark may be received from the opposite extremity, thereby showing that the iron is a conductor of electricity.

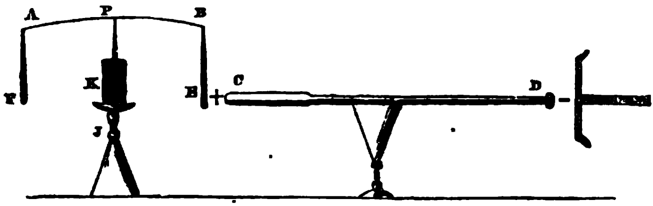


Fig. 17.

To show the induction of electricity in this case, bring the electrified plate of the electrophorus near to one extremity D of the poker, but not so near as to transmit a spark; then a spark of positive electricity may be received from the opposite extremity C.

The tin-foil needle electroscope. — In order to render the law of induction more apparent, construct an electroscope A P J. (See Fig. 17.) Take a strip of card paper A P B about six inches long, and half an inch wide; attach narrow strips of tin foil to the extremities of the card paper, by means of insulating knobs of sealing wax, and balance the card paper, on a small indentation made at its centre, on the point P of a pin passed through a cork and placed on the top of a wine glass J. With the view of adjusting the balance, two small rings of Indian rubber are placed on the card, one on each side. This will form a delicate electroscope, which may be used in conducting some interesting experiments hereafter to be described.

Bring the strip of tin foil, of this electroscope, near to the one extremity of the poker, (see Fig. 17,) and then bring the insulated plate of the electroscope near to the other extremity, and the needle will be deflected, the tin foil being electrified with positive electricity: touch the extremity C with the finger, then take away the plate of the electrophorus, and the needle of the electroscope will return to its first position; for the poker will be left in a negative state of electricity, while the tin foil of the electroscope will be in a positive state; and so on to other experiments of this kind, illustrating the great law of electrical induction.

A remarkable case of induction. — Place a small tea tray T upon a dry wine glass J, and upon this tray place the electroscope just described, as shown in Fig. 18; charge the tea tray T with positive electricity, by

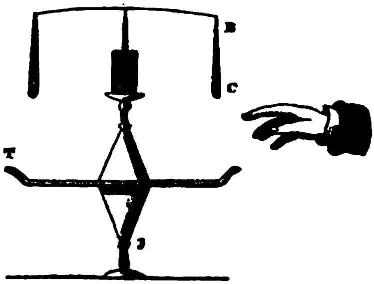


Fig. 18.

means of the electrophorus, described at page 220; then, because the tin foil C B is insulated by the action of induction, the lower extremity C will be negative, while the upper extremity B is positive. Touch the upper extremity B of the tin foil C B, and it will remain charged with negative electricity; now bring the hand over the tray, near to the extremity C of the tin foil, and it will be instantly repelled, giving the appearance of the hand as being negatively electrified, which, in fact, it really is from the induction of the tray T.

To electrify a tin plate, either negatively or positively, by means of the electrophorus. — (1.) Place the tin plate A upon a dry wine glass, (see Fig. 19;) charge the plate B of the electrophorus positively, after the manner described at page 220, and bring it near to the insulated plate A, (without allowing a spark to pass from the one to the other;) touch the plate A, and a spark of *positive* electricity will be received from the inductive action of the plate B; first take away the knuckle, and then take away the plate B, and the plate A will remain charged with *negative* electricity.

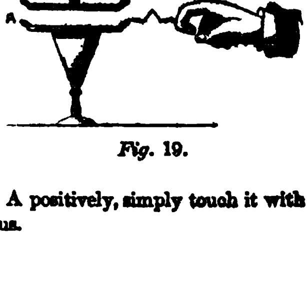


Fig. 19.

(2.) To electrify the insulated plate A positively, simply touch it with the charged plate B of the electrophorus.

To exhibit the dancing balls. — Put a few small pith balls into the plate A, (see Fig. 19;) bring the electrified plate B over them, as shown in the figure, and they will appear to jump up and down.

The electric bell. — Place a damp wine glass C (as shown in Fig. 20) near to the insulated plate A; suspend a small brass ball or button D from a dry silk thread between the glass and the plate; electrify time after time the plate A by means of the electrophorus; and the ball D will oscillate between the plate and the glass, thereby producing a tinkling sound.

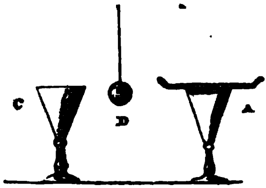


Fig. 20.

The electrical pendulum. — This instrument is represented in Fig. 21. A and B are two insulated plates; the one is charged with positive, and the other with negative electricity; E F is a strip of card paper, having

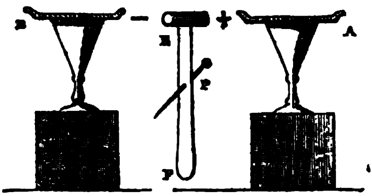


Fig. 21.

a pin P passed through it, and a piece of pith E attached to its upper extremity by means of an insulating knob of sealing wax; the pin P of the pendulum E F is supported on the edges of two wine glasses, which are not shown in the cut The apparatus is adjusted so as to allow the insulated pith E to oscillate between the edges of the plates A and B. With the view of causing the lower extremity F to preponderate, a small sliding ring of Indian rubber is placed on the portion P E of the pendulum.

The electrical hammer. — This simple piece of apparatus is represented in Fig. 22. Here the pendulum E F of the apparatus just described is supported in a horizontal position in the manner already described; the pith knob E, in this case, oscillates between the electrified plate A and a conductor D.

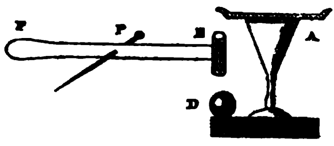


Fig. 22.

Tate's electrical revolver. — This simple and interesting piece of apparatus is represented in Fig. 23. F and E are two insulated plates charged with different kinds of electricity, (see p. 222;) A B J is the tin foil electroscope, described at page 221, placed between the electrified plates

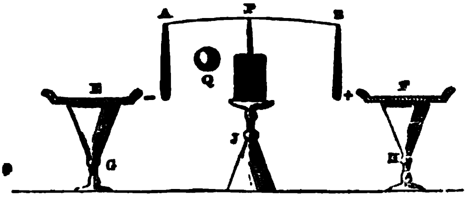


Fig. 23.

E and F, so that the lower extremities of the strips of tin foil may nearly touch the plates E and F. When the plates are electrified, the electrical needle A B rapidly revolves upon its centre P; the plates charge the insulated strips of tin foil as they pass them, so that the plates attract the strips of tin foil when they are on one side, and repel them when they are on the other side. The charge of the plates must be from time to time renewed. The action of the instrument is improved by placing a conducting knob Q midway between the two plates E and F, so as to discharge the electricity of the strips, as they pass the conducting knob.

All the apparatus we have hitherto described may be easily constructed, at a very small cost, by any person of ordinary skill and patience.

ELECTRICAL MACHINES.

12. Electrical machines are used for generating electricity by friction on a large scale. They consist of three leading parts. The rubber is a soft hair *cushion*, covered with leather or with some substance which readily generates electricity by friction. The body on which the rubber acts is either a *glass cylinder* or a circular *glass plate*, which turns upon an axis. The receiver of the electricity is called the *prime conductor;* it is a thin brass cylinder, or a brass rod, mounted on a glass pillar, or some insulating material. The action of an electrical machine is simply this: the glass cylinder, or the glass plate, as the case may be, upon being turned, rubs against the cushion, and thereby generates electricity upon the surface

of the glass, which is continually carried round to the prime conductor.

The common Cylindrical Machine.

13. Fig. 24 represents an electrical machine of this kind. The glass cylinder A B, which rests on an axis passing through C, is made to revolve by means of the wheels C and D connected by a band, the wheel D being turned by means of the handle R; the cushion H, which rubs against the cylinder, is mounted on a glass pillar I, which slides in a groove at the foot, for the pur

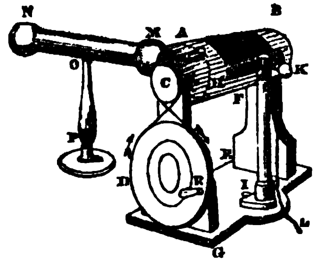


Fig. 24.

pose of adjusting the pressure upon the cylinder; the chain K L connects the cushion with the ground; a flap B of varnished silk passes from the cushion over the cylinder, for the purpose of preventing the escape of the electricity into the air; the prime conductor M N, mounted on the glass pillar O P, has a row of points projecting from the extremity M, and coming nearly in contact with the surface of the glass cylinder. As glass is liable to collect moisture on its surface, it is usual to cover all the insulating pillars, as well as all those parts of the cylinder which do not touch the cushion, with a coating of varnish, which has a higher insulating property than glass.

Fig. 25 shows the construction of the cushion; where H is the rubber, with an adjusting spring fixed behind it, for keeping it continually pressed against the cylinder; K the brass knob, or ball, for attaching the chain.

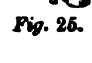


Fig. 25.

Fig. 26 shows the form of the row of points attached to the prime conductor.

When the cylinder is turned round by the handle R, positive electricity is generated on the surface of the cylinder, and negative electricity on the cushion. The latter is carried off by the chain to the ground. The positive electricity is carried round to the points of the prime conductor, where it acts by induction on the natural electricity in the conductor — that is, by attracting the negative fluid, and repelling the positive. The negative fluid, escaping by the points, unites with the positive fluid on the cylinder, and thereby restores the surface of the cylinder to its natural state, so that when it arrives again at the rubber it is prepared for another charge of positive fluid; at the same time

Fig. 26.

the prime conductor is left charged with positive electricity. According to this theory, the negative electricity of the conductor is continually passing off by the chain attached to the cushion, which constantly keeps the conductor charged with positive electricity. By detaching the chain from the cushion, and placing it on the prime conductor, we are able to charge the cushion with negative electricity.

With the view of increasing the efficiency of the machine, the cushion is covered with an amalgam of zinc and tin. According to Singer, the best composition of the amalgam is two parts by weight of zinc, one of tin, and six of mercury. The mercury is added to the mixture of the zinc and tin when in a fluid state, and the whole is then shaken in a wooden box until it is cold; it is then reduced to a powder, and mixed with a sufficient quantity of lard to reduce it to the consistency of paste. A thin coating of this paste is spread over the cushion; but before this is done, all the parts of the machine should be carefully cleaned and warmed. Black spots and lines are readily taken from the glass by applying a rag dipped in spirits of wine; and the efficiency of the machine is greatly promoted by applying with the hand a piece of leather covered with amalgam to the cylinder.

The common Plate Machine.

14. Fig. 27 represents a machine of this kind. A B is a circular plate of glass, turning on a horizontal axis C by means of the winch or handle D; the plate is embraced at E by two cushions, the pressure of which is adjusted by screws; two similar cushions are placed at E′; flaps, proceeding from the cushions, cover the glass at the spaces shown in the figure to about half an inch from the points on each side of the conductor; the conductor P O M F is a small brass tube, or cylinder, bent so as

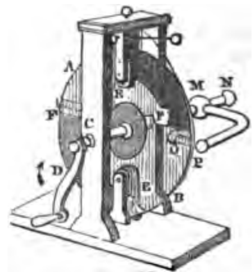


Fig. 27.

to suit the plate, and supported by a glass rod F′ M attached to the upright frame E; P Q, running parallel to the surface of the plate, is that part of the conductor which carries the points, and a similar bent branch with points is formed at F. When the handle D is turned in the direction of the arrow, the cushions at the top, as well as those at the bottom, generate electricity; the points at F receive the electricity generated by the cushion E, whilst those at P O receive the electricity generated by E′. In order to prevent the escape of electricity, all the extremities of the conductor are terminated in brass balls or globes. The

principle on which this machine acts is precisely the same as that of the common cylindrical machine. This machine is more powerful than the cylindrical one; but the difficulty of insulating the rubbers, so as to obtain the negative fluid, is certainly an objection to it.

The Haerlem plate machine, represented in Fig. 28, fully remedies this deficiency in the common plate machine. The glass plate is fixed to the axis D; the two cushions are insulated on glass pillars E and F; C B C′ is the bent arm of the prime conductor, armed with points, and insulated on the glass pillar G; in order to connect the cushions with the ground, there is a bent or semicircular conductor, similar to C B C′, proceeding from the axis at D, and reaching to the balls of the two cushions.

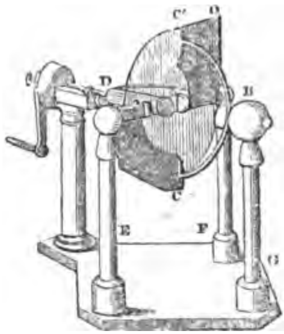


Fig. 28.

When it is required to charge the conductor B with negative electricity, the semicircular rod C B C′ is moved into a horizontal position, thereby bringing the points opposite to the two cushions; at the same time the other semicircular rod, on the opposite side of the plate, is moved round into a vertical position, thereby bringing its points at the top and bottom parts of the plate.

Fig. 29 represents another form of the plate machine; where C is the

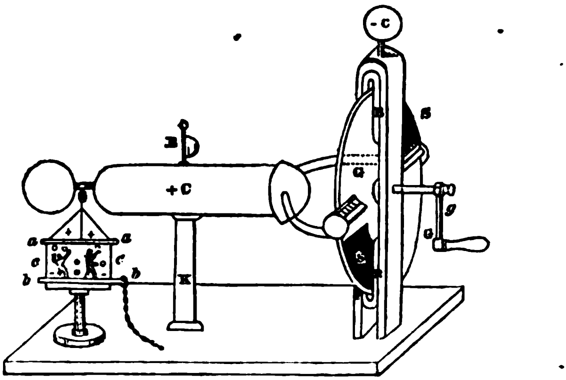


Fig. 29.

prime conductor, mounted on the glass pillar K; G G the glass plate; *g* the winch; B R the cushions; S S′ the flaps, &c.; E a quadrant electrometer inserted in the conductor, to determine the quantity of electricity with which it may be discharged; and *a a*, *b b* an apparatus suspended from the conductor to illustrate the principle of electrical attraction and repulsion.

APPENDAGES TO ELECTRICAL MACHINES.

15. *The insulating stool*, represented in Fig. 30, consists of a board of hard, well-baked wood, supported on glass legs covered with varnish. It is useful for insulating any body charged with electricity; for instance, a person may stand upon the stool and become charged with electricity, upon being put in connection with the prime conductor of the electrical machine.

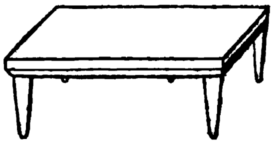


Fig. 30.

Discharging rods are brass rods terminating with balls, or with points fixed to glass handles. With these rods, electricity may be taken from a conductor without allowing the electrical charge to pass through the body of the operator.

Fig. 31 represents a common discharger; where A is the glass handle, C E D the brass rod, C and D the balls.

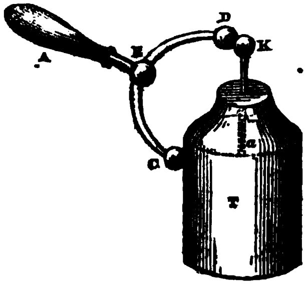


Fig. 31.

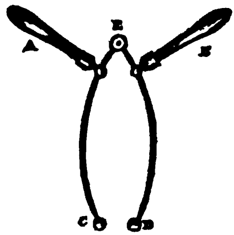


Fig. 32.

Fig. 32 represents a double-handled jointed discharger; where A and B are the glass handles, E the joint, &c.

The Leyden jar consists of a glass cylinder, or wide-mouthed bottle, T,

(see Fig. 31,) both surfaces of which are coated with tin foil up to about three inches of the top. The coating of tin foil on the outside of the bottle is called the outer coating; the other, on the inside, is called the inner coating. Electricity is transmitted to this coating by means of a metal rod K *a*, terminated at the upper extremity by a knob K, and at the lower extremity by a chain which comes into contact with the inner coating of the jar. The rod is fixed by passing tightly through a wooden plug, which fits firmly into the neck of the jar. Those portions of the glass which are not coated with the tin foil are covered over with a thick coating of wax, to prevent a reunion between the electricity of the outer coating and that of the inner coating. When the jar is to be charged, it is held in the hand by the outer coating, and the knob K is brought near to the conductor of the electrical machine. While spark after spark of positive electricity enters the jar, the positive electricity, on the principle of induction, is driven off from the outer coating; so that while the inner coating becomes charged with positive electricity, the outer coating becomes charged with negative electricity in a manner which will be hereafter more fully explained. When the jar is to be discharged, the operator, holding the discharging rod by the glass handle A, brings one knob C in contact with the outer coating, and then gradually brings the other knob D near to the knob K of the jar; the reunion of the two fluids (the positive from the inner coating, and the negative from the outer coating) takes place between the two knobs D and K with a bright spark and a snapping noise.

The universal discharge, represented in Fig. 33, consists of a dry deal,

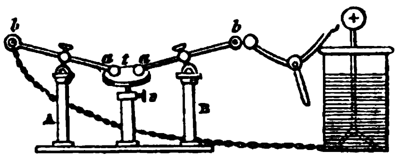


Fig. 33.

on which two glass pillars A and B are fixed; two brass rods *a b* and *a b*, capable of turning, on a ball and socket joint, in any direction, and also capable of sliding in the top balls; the knobs *a a* are applied to a wooden table *t*, which admits of being raised or depressed by means of an adjusting screw *v*; a narrow strip of ivory is inlaid across the table; the knobs *a a* may be screwed off, and replaced by points or by forceps. This piece of apparatus is much used for passing strong charges of electricity through any substance.

The quadrant electrometer. — This instrument is used for indicating the quantity of electricity accumulated in the prime conductor of the machine. It consists of a vertical stem or rod, which admits of being inserted in a hole made in the prime conductor; to the side of this stem is fixed a graduated quadrant, carrying a light needle or rod, terminated by a pith ball; this light needle turns on a pivot O fixed in the centre of the quadrant. When the machine is not in action, the light needle hangs parallel to the vertical stem; but when the machine is worked, the needle is repelled from the stem, and the height to which it ascends indicates the amount of electricity accumulated in the prime conductor.

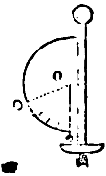


Fig. 34.

16. A FEW EASY EXPERIMENTS WITH THE ELECTRICAL MACHINE.

Exp. 1. Work the machine; bring your knuckle near to the prime conductor; a vivid and instantaneous flash, accompanied with a snap-

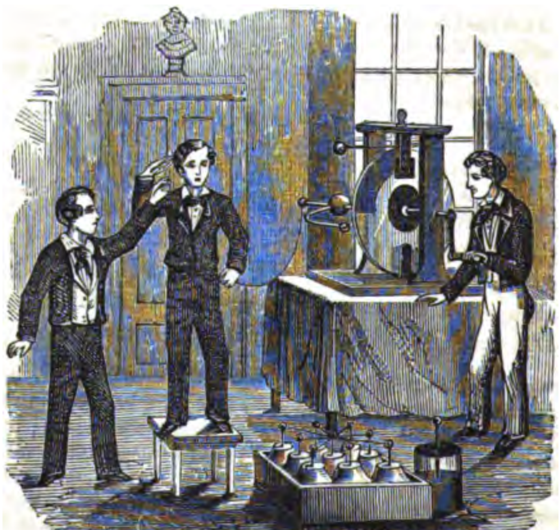


Fig. 35.

ping noise, passes between the conductor and your hand, which produces a slightly painful sensation: this is the electric spark.

A spark will be communicated to any conductor. Hold a stick of sealing wax, or any other non-conductor, to the prime conductor: no spark will be received.

Exp. 2. Fix the quadrant electrometer on the prime conductor; work the machine, and observe to what height the pith ball is repelled. Hold the point of a sewing needle near to the conductor: the pith ball of the electroscope instantly falls. Take sparks from the conductor: the pith ball falls at the instant each spark is taken.

Exp. 3. Let a boy stand on the insulating stool, and let him place one of his hands on the prime conductor; work the machine; take sparks from his body: see how he winces from the smarting sensation they produce, especially when taken through his clothes! (See Fig. 35.)

Exp. 4. Charge a Leyden jar fully, and discharge it with the jointed discharging rod: see what a vivid spark it gives!

Charge the Leyden jar (with about half a dozen sparks;) grasp the outer coating with one hand, and touch the knob with the other. The electric fluid, in passing through your body, gives you what is called an *electric shock.*

Let a few boys form a ring by taking hold of each other's hands; let the first boy in the ring grasp the outer coating of the charged jar, and let the last boy touch the knob: instantaneously all the boys in the ring will receive a shock.

ELECTRICAL ATTRACTION AND REPULSION.

17. This subject has been fully explained in the preliminary portion of this work, in relation to a numerous class of simple experimental facts. But the electrical machine enables us to exhibit the various phenomena of electrical attraction and repulsion in the most striking manner.

Exp. 1. *Repulsion of electrified threads.* — Take a skein of linen threads, and, after tying them together at each end, suspend them from the prime conductor of the machine. When the handle of the machine is turned, the threads will become electrified, and will repel each other, so that they will swell out in the middle, forming a figure resembling the meridian lines on a globe.

Exp. 2. *The frightened head of hair.* — Fix a doll's head of hair in the prime conductor; work the machine, and the hairs will appear to stand on end, from their mutual repulsion, presenting an exaggerated appearance of a person in a state of fright.

Present a pointed rod to the hairs, and they will immediately collapse.

A bunch of large, downy feathers, inserted into the hole of the prime conductor, will present a similar appearance.

Exp. 3. *The electrical dance.* — In this experiment, a metal plate is suspended by a chain from the prime conductor; a few inches below this plate another plate is placed in connection with the earth; and some light figures are placed upon the bottom plate, as shown in Fig. 36. When the machine is worked, the figures appear to dance, or to jump up and down, from the one plate to the other, in a very grotesque manner.

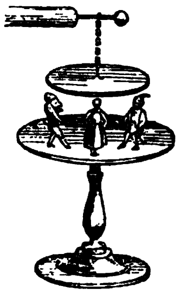


Fig. 36.

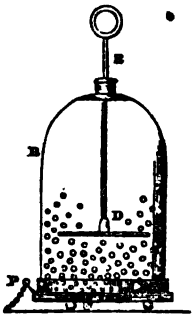


Fig. 37.

Exp. 4. *The dancing balls.* — Here a number of cork or pith balls are placed upon a metal disk P (Fig. 37) communicating with the ground, and the whole of them are covered with the glass bell B, whose upper part is open, and provided with a collar of leather, through which a rod R D passes, carrying at its lower extremity a metal disk D. By this construction, the upper disk D can be placed at any convenient distance from the lower disk P. The ring R of the rod is put in communication with the prime conductor, so that, when the machine is worked, the balls are attracted by the plate D, and then repelled from it, being charged with positive electricity; now, when they touch the bottom plate P, the electricity is taken from them, and they are thus prepared to be again attracted by the plate D, and so on.

We may make this experiment in a more simple manner by using a glass tumbler, (Fig. 38,) whose interior surface has been electrified by touching its different parts with the pointed extremity of a metal rod fixed in the conductor of an electrical machine in action. The glass is then inverted upon a table, over a lot of pith balls; the balls immediately

begin to dance, being alternately attracted and repelled by the electric fluid on the interior surface of the glass, as shown in Fig. 38.

Fig. 38.

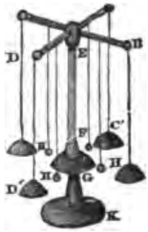


Fig. 39.

Exp. 5. *The electrical bells.* — The alternate attraction and repulsion of electrified bodies is beautifully illustrated in this piece of apparatus, which is of some importance, inasmuch as it is frequently employed in tropical countries to detect the presence of an electrified cloud. A glass pillar supports two metal rods, A B and C D, from which four bells, A′ B′ C′ D′, are suspended by chains. A central bell G, at the foot of the glass pillar E F, is placed on the wooden stand K; a chain G K connects this bell with the ground. From the extremities of the rods A B and C D, four small brass balls H H are suspended by silken threads. When the machine is in action, the cross rods are put in connection with the prime conductor, and the four bells A′ B′ C′ D′ become charged with electricity, and consequently attract and repel the insulated balls H H. When the balls H H are repelled, they strike the bell G, to which they give up the electricity they received from the electrified bells, and this electricity is carried off by the chain G K. The tinkling noise thus produced will continue so long as electricity is supplied to the bells A′ B′ C′ D.

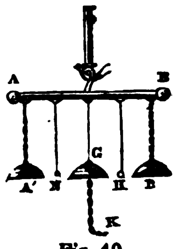


Fig. 40.

Fig. 40 represents a simpler apparatus of this kind, where the bells are hung from a brass rod A B, which may be suspended from the prime conductor. In this form of the apparatus, the central bell is suspended by a silken thread, and is connected with the ground by means of the chain G K.

Exp. 6. *The electrical seesaw.* — This consists of a small strip of wood (see Fig. 41) about a foot long, covered with tin foil, and insulated on *c* like a balance.

A slight preponderance is given to it on the side *a*, where it rests on a metal ball *m* at the top of a brass wire; *p* is an insulated metal ball. The ball *p* is connected with the interior coating of an electrical jar, while *m* is connected with its exterior coating. When the jar is charged, the seesaw motion will immediately be produced. The cause of this motion depends upon the common principle of electric attraction and repulsion.

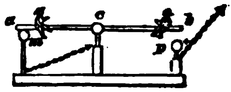


Fig. 41.

This experiment will succeed quite as well by simply connecting the ball *p* with the prime conductor of the machine, and the ball *m* with the ground.

Exp. 7. *The electrified water.* — Here a little metal bucket B, having a small hole in its bottom, is suspended from the prime conductor of the electrical machine. The hole in the bucket is so small that the water merely falls from it in drops when the machine is not in action; but when the machine is worked, the water runs from the hole in a continuous stream, owing to the repulsion which takes place amongst the particles of the electrified water.

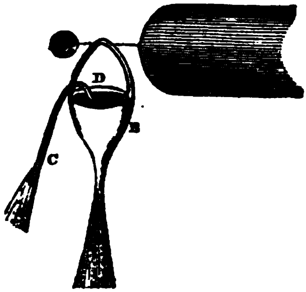


Fig. 42.

The same experiment may be performed by inserting a siphon D C, having a small bore, into the water, as shown in Fig. 42.

A similar effect would be produced by suspending a sponge, saturated with water, from the prime conductor of the machine.

Exp. 8. *Electrified sealing wax.* — Ignite the extremity of a stick of sealing wax, and when it is in a full state of fusion, blow out the flame and bring the melted wax near to the prime conductor of the machine; numerous fine filaments of wax will fly to the conductor, and will adhere to it, forming upon it a sort of network like wool. This is a simple case of electrical attraction. The experiment will succeed best if a small piece of wax is attached to the end of a metal rod.

Exp. 9. *The electrical swing* consists of a light figure placed upon a swing formed by a silk thread. The light figure swings between two balls, one of which is insulated and put in connection with the prime conductor, the other ball being put in connection with the ground. The principle of this apparatus is the same as that of the electrical seesaw.

Exp. 10. *The electrical swan.* — In this experiment a light piece of cork, or any other light substance, cut in the shape of a swan, is made

to float in a basin of water placed upon the insulated stool. The water is electrified by means of a chain which passes from it to the prime conductor. The little floating swan will approach any non-electrified substance that may be presented to it.

In making this experiment, the cork should be first completely immersed in water, to render it a conductor of electricity.

Exp. 11. *The electrical spider.* — An electrical jar L has a ball *b* connected with its exterior coating. When the jar is charged with the positive electricity of the prime conductor, any light substance, such as a representation of a spider, suspended between the knobs *a* and *b*, will oscillate between them.

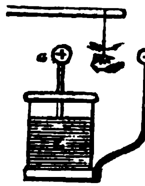


Fig. 43.

LUMINOUS EFFECTS OF ELECTRICITY.

THE ELECTRIC SPARK.

18. When the knuckle, or a brass ball at the end of a rod, is presented to the conductor of a machine in full action, a spark is produced by the passage of the fluid from the conductor to the knuckle. The spark has a zigzag form, similar to a flash of forked lightning. The length and intensity of the spark depend upon the power of the machine. Sparks may be taken from the prime conductor of a very powerful machine at the distance of twenty or thirty inches. When the continuity of a conducting substance, such as tin foil, is broken at different parts, a spark will be produced at every place where the course of the conductor is broken. A great variety of beautiful experiments may be made to illustrate this principle. These experiments should be made in the dark.


Fig. 44.

Exp. 1. *Luminous spangles.* — Sew a number of tin foil spangles on silk ribbon, about a quarter of an inch apart; hold the ribbon by one extremity, and bring the other near to the prime conductor; the elec-

tricity, in its passage from spangle to spangle, will form a beautiful line of light.

Exp. 2. *The spiral tube.* — This consists of two glass tubes, about a foot long, one of which is placed within the other. The inner tube has spangles of tin foil pasted on its outside surface in the form of a spiral. The two ends of the tubes are mounted with brass caps. Hold the tube by one of the brass caps; apply the other cap to the prime conductor; a beautiful spiral stream of electric light will pass from one end of the tube to the other.

Fig. 45.

A spiral tube, made to revolve within an electrified hoop produces a splendid effect.

Spangles of tin foil may be pasted on common window glass so as to produce various luminous devices, such as geometrical figures, or short words.

Exp. 3. *Ignition of spirits of wine.* — Let a person, standing on the insulating stool, (see Fig. 35,) lay one hand on the prime conductor, and with the other hand let him hold a warm teaspoon containing spirits of wine; let some other person present his knuckle to the spoon, and the passage of the spark will cause the spirits to ignite.

Exp. 4. *Ignition of ether on water.* — Pour some water into a wine glass, whose outer surface is perfectly dry; pour some ether on the top of the water, and connect the water, by means of a chain, with the prime conductor of the machine. Turn the handle of the machine, and present your knuckle, or a metallic ball, to the surface of the ether, and the electric spark will ignite the ether.

Exp. 5. *The electrical pistol.* — The electric spark will readily cause a mixture of hydrogen and common air to explode. The electrical pistol, represented by Fig. 46, is commonly employed for this purpose; *a* is a brass tube, or barrel, open at one end; *b* is a copper wire, insulated by its being inserted in an ivory tube, which passes through one side of the barrel, and nearly touches the inner surface of the opposite side. Hold the mouth of the pistol over a stream of hydrogen gas, proceeding from a pipe; after a sufficient quantity of gas has entered, close the mouth of the pistol with a cork *c*; take a spark through the knob *b*, and the cork will be discharged with a loud report, from the explosion of the gas by the passage of the spark from the extremity of the wire to the inner surface of the barrel. In order to avoid any accident, the cork should be attached to the pistol by a loose string.

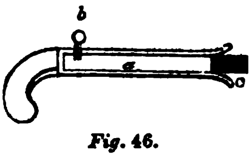


Fig. 46.

Exp. 6. *Ignition of common gas.* — Let a person, standing on the insulated stool, touch the prime conductor with one hand, and with the knuckle of the fore finger of the other hand let him transmit a spark to the orifice of a gas pipe from which a current of gas is being discharged, and the gas will be ignited.

Bring a candle with a long snuff, that has just been extinguished, near to the prime conductor, so that the spark passes from the conductor, through the smoke, to the candle; it is relighted.

DIFFERENT FORMS OF THE ELECTRIC LIGHT.

19. The intensity of the electric light depends, not only upon the density of the accumulated electricity, but also upon the density and nature of the gas through which the spark passes. Thus the spark is bright and short when it passes through dense air; but when it passes through rarefied air it is long and diffused, and of a violet hue. The color of the spark is also much influenced by the composition of the gas through which it is transmitted, as well as by the nature and form of the conductor. In this way a great variety of surprising and beautiful luminous experiments may be performed.

Exp. 1. *The electric light from points.* — Place a pointed rod in the prime conductor charged with positive electricity, and the electric light will issue from the point in the form of a brush. Try to take a spark from the conductor, when the pointed rod is attached to it.

Fig. 47.

Hold the point of the rod towards the prime conductor, and a *star* will be seen on the point.

Attach the pointed rod to the insulated cushion, charged in this case with negative electricity, and the electric light will be seen in the form of a star.

Insulate the cushion as well as the prime conductor, and attach pointed rods to each of them, so that the points may be at the distance of four or five inches from each other; then, upon working the machine, a brush will be seen upon the point attached to the prime conductor, while a star will be seen upon the other point, presenting the appearance as if the conductor gave out its electricity, while the cushion received it.

These phenomena were at one time considered as strong arguments in favor of Franklin's theory of electricity.

Exp. 2. *Passage of the electric light through rarefied air.*—Fix a wire, terminated by a brass ball, to the plate P of an air pump; attach a similar ball (by a sliding wire A B) to the top of the receiver R, so as to bring the one ball over the other, and at the distance of about one inch apart. Connect the outer ball B with the prime conductor, and the bottom plate P with the insulated cushion. Upon turning the handle of the machine, a continuous stream of electric light will pass from the positive to the negative ball. While no light is exhibited by the positive ball, a beautiful luminous atmosphere entirely surrounds the negative ball, giving the appearance of a fluid in the act of passing out of the one ball and entering into the other. By altering the distance of the balls from each other, different aspects may be given to the electrical light.

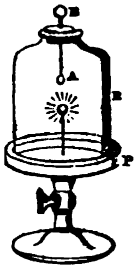


Fig. 48.

Exp. 3. *The electrical aurora borealis.*—Instead of the receiver R of the last experiment, let a glass tube, about twenty inches long and three inches in diameter, be used; and instead of the two discharging balls, let two points be substituted. When the tube is exhausted of air, and the machine is worked in the dark, the whole length of the tube will be one sheet of violet red light; if a small portion of air be admitted, numerous flashes will issue from the points, and traverse the tube; when a little more is admitted, these flashes will appear to glide in a serpentine manner down the interior of the tube. The succession of luminous phenomena, in fact, bears a striking resemblance to the aurora borealis.

An *aurora flask*, sold by instrument makers, answers very well for exhibiting these phenomena.

Exp. 4. The electric spark is blue when transmitted through nitrogen.

Exp. 5. *Passage of the electric light through the Torricellian vacuum.*—Seal a short wire within one end of a glass tube about 32 inches long; attach a brass ball to the external end of the wire; fill a dry tube with mercury, and invert it in a cup of mercury; a vacuum will be formed in the upper part of the tube; connect the ball with the prime conductor; turn the machine, and a current of violet-colored light will pass through the vacuum.

MECHANICAL EFFECTS OF ELECTRICAL POINTS.

20. When the electric fluid discharges itself from a pointed conductor, a *reaction* or *recoil* is produced, which may be

used to give motion to certain delicate pieces of mechanism, in the same way as fluids are employed in the common reaction machines.

Exp. 1. *The electrical wind.* — Fix a pointed rod on the prime conductor; work the machine; bring the back of your hand near to the point, and you will distinctly feel the electrical wind proceeding from the point.

Bring the flame of a candle near to the point; the flame will be extinguished by the electrical wind, chiefly caused by the repulsion of the electrified air from the point.

Exp. 2. *The electrical fly wheel.* — A metal cross turns on a pivot which is fixed on the prime conductor; the points of this cross are all bent in the same direction; when the machine is turned, the fly revolves in the directions of the arrows shown in the figure; that is, contrary to the direction in which the points are bent.

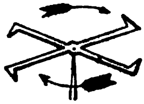


Fig. 49.

The fly is sometimes mounted on an insulated stand, as shown in Fig. 50.

Exp. 3. *The electrical orrery.* — This instructive and elegant piece of apparatus is represented by Fig. 51; where S represents the sun, E

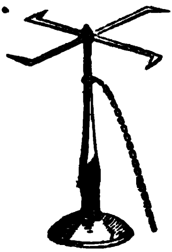


Fig. 50.

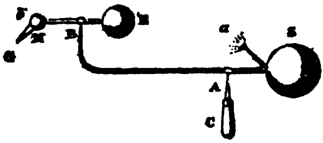


Fig. 51.

the earth, and M the moon. The earth and the moon turn upon the pivot B, and the sun, with the earth and the moon, turn upon the pivot A, which is placed in their common centre of gravity. The point A C is fixed on the prime conductor. The points *a* and G are so placed that all the pieces revolve in the same direction; that is, from west to east.

Exp. 4. *The electrical inclined plane.* — Here the recoil of the electrical discharge from the points causes the fly to roll up an inclined plane formed by two wires A B and C D, supported by insulating pillars.

One of the wires is connected with the prime conductor by means of the chain C K.

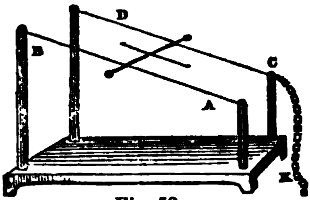


Fig. 52.

Exp. 5. *Repulsion of a Point.* — Bring an insulated point, connected with the prime conductor, near to the electrical swan, (see Exp. 10, p. 234;) then, instead of being attracted, it will be repelled. This is caused by the repulsion of the electrified air from the point.

On this principle, a light paper wheel may be made to revolve upon a pointed conductor being presented to its sails.

The following remarkable experiment depends upon the same principle: —

Pieces of phosphorus are put into the two metal cups A and B insulated on glass pillars; a candle C is placed exactly between them; the cup A is connected with the prime conductor, and the cup B with the insulated cushion; when the machine is worked, the electric wind, blowing from the positive cup A to the negative cup B, causes the flame to fly towards the cup B, and to heat it, so as to ignite the phosphorus.

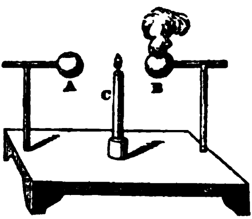


Fig. 53.

This experiment was at one time thought to be a decided argument in favor of the single fluid theory; but the phenomenon may be satisfactorily explained upon the theory of two distinct fluids.

PECULIAR APPLICATIONS OF THE PRINCIPLE OF INDUCTION.

21. The principle of induction has already been explained; but the following experiment, made with the electrical machine, will render it more apparent.

Exp. 1. Take an insulated metal cylinder B, and attach small pith balls, suspended from cotton threads, to different parts of its surface; gradually bring an electrified body A, which has been charged with the prime conductor, near to this cylinder; when A is about an inch from the conductor, no spark having passed from A to B, the pith balls at the extremities C and D diverge; at E and F the divergence is less than it

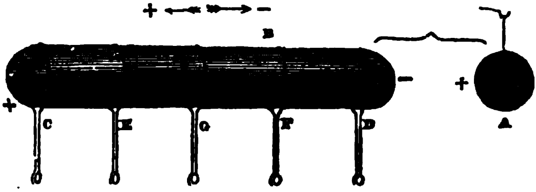


Fig. 54.

is at C and D; and at or near the centre G the balls do not diverge at all.

As we have already explained, the positive fluid is driven to the extremity C, and the negative fluid is drawn to the extremity D.

When A is withdrawn, all the balls fall back to their natural position, and the positive and negative fluids on the conductor B reunite and return to their natural state — all electricity disappears.

Before withdrawing A, touch the extremity C, so as to take away the positive fluid, and the conductor will remain charged with negative electricity, and so on as described in the experiments given at page 222.

Electricity may be developed by induction in a series of insulated conductors, placed in a line, with their extremities in order near to each other.

The Electrophorus.

22. The electrophorus, invented by Volta, depends upon the principle of induction; it is capable of retaining for a considerable time the electricity developed upon its non-conducting surface by friction. It is composed of a cake of resin poured into a circular metal mould or plate *b b*, of a disk of metal *a a*, a little less than the cake, furnished with an insulating handle *g*. The cake of resin is electrified negatively by rubbing its surface with a cat's skin; the metal disk is then placed upon the excited cake; we then touch the plate with the finger, which gives us a spark of negative electricity, and raise it by the handle *g*, when it will be found charged with positive electricity; upon touching the plate, we receive a spark of positive electricity.

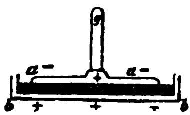


Fig. 55.

When we first touch the metal plate, (while in contact with the resin,) the negative electricity is taken away from it, owing to the repulsion of the negative fluid of the cake; now, when the plate is raised by

the insulating handle, it is charged with positive electricity, because the negative fluid had been taken away from it, while the positive fluid in it remained by the attraction of the negative fluid of the cake.

As the cake will retain its electricity for a very long time, any number of sparks may be taken from it with scarcely any diminution of intensity.

The experiments given in connection with Fig. 19, page 222, may be explained on the same principle as that of the electrophorus.

Tate's Electrophoric Machines.

23. The intensity of the electricity transmitted to the conductor by the electrophorus, described at page 220, depends upon the following circumstances: (1.) The size of the plate; (2.) The completeness of the contact of the plate; (3.) The rapidity with which the strokes are performed.

The following contrivances will give power to the instrument, by facilitating the operation, and by lessening the time required for performing each stroke.

Double-acting Electrophorus, or an Electrophorus capable of producing both Kinds of Electricity.

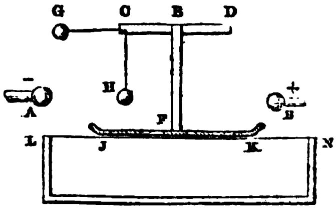


Fig. 56.

24. This simple contrivance is represented in Fig. 56. L N is an open box; L N sheet gutta percha stretched tight over its top; J K the plate of the electrophorus; E F a strip of double gutta percha attached to the plate for the purpose of lifting it, forming a loop at the top for receiving an insulating rod D C, which may be a rod of glass or a stick of sealing wax; G C H a bent, insulated wire, terminated with knobs G and H; A an insulated conductor for receiving the negative electricity; B another insulated conductor, for receiving the positive electricity; these conductors are placed at the distance of six or eight inches from the plate J K, and the length of the wire C H is such as to allow the knob H to come into contact with the plate J K at the same time as the knob G comes into contact with the conductor A. The machine is worked in the following manner: —

Rub the surface of the gutta percha with a piece of fur or rabbit's skin; place the plate J K upon the excited sheet, taking care to hold it by the insulating handle C D; depress the handle C D, until the knob H comes in contact with the plate J K; then a spark of negative electricity will be transmitted to the conductor A; raise the plate J K by means of the insulated handle until it strikes the conductor B; then a spark of positive electricity will be transmitted to the conductor; and so on to an almost indefinite number of times. The action of the machine simply consists in raising and depressing the hand.

It will be observed that, at each upward stroke, the knob G is raised from the conductor A before the plate J K is lifted off the gutta percha.

The conductors A and B may be used in the same way as the conductors of an ordinary electrical machine — that is, for charging jars, &c.

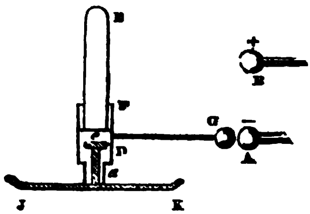


Fig. 57.

Fig. 57 represents another form of this machine, which possesses some advantages over that just described. J K represents the plate; A and B the conductors, already described; E F an insulating handle, of sealing wax, or glass covered with sealing wax, cemented into a metal tube F D, which is fixed to a smaller tube *a* coming in contact, time after time, with the plate J K; this tube *a* works smoothly on a brass rod *e* fixed to the plate J K, having a stop, or small rim, at its top, for the purpose of stopping the ascent of the small tube *a*; F G is a wire fixed to the tube F D, and terminated by a knob G. By this contrivance the rod F G admits of an up and down motion upon the pin *e*, at the same time that the plate J K admits of being lifted off the gutta percha. The machine is worked in the following manner: —

Hold the plate by the handle E, and place it upon the excited gutta percha L N, (see Fig. 56;) depress the handle E until the knob G comes into contact with the conductor A, and a spark of negative electricity will be transmitted to it; raise the handle until the knob G comes into contact with the conductor B, and a spark of positive electricity will be transmitted to it; and so on, as before described.

Single-acting Electrophorus.

25. The plates, with their peculiar appurtenances, just described, may be employed with great advantage in the place of the simple insulated plate described at page 220. The contrivances connected with these plates enable the operator to perform each stroke more rapidly, leaving,

at the same time, his left hand free to be used in any matter requiring his attention. All that is required in the application of these plates to the common sheet electrophorus is simply to have a conductor placed so as to come in contact with the knob G at the moment the plate J K falls upon the excited gutta percha.

Disguised Electricity. Condensers.

26. If a conductor connected with the ground be brought near to one extremity of another conductor charged with electricity, then the quantity of the electric fluid at that extremity will be considerably increased. This fact is just what we should have anticipated from the peculiar properties of the electric fluid.

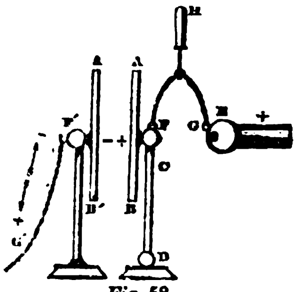


Fig. 58.

Let A B be an insulated plate charged with electricity, (say with + electricity;) A′ B′ another plate, connected with the ground by means of the chain F′ G′. Connect A B with the prime conductor by means of the jointed discharger G H F; remove the jointed discharger: then A B will become charged with positive electricity, which will have the same intensity as that of the prime conductor; bring the plate A′ B′ near to the charged plate A B: then the electricity on its surface will be considerably increased. For whilst the positive electricity of A B repels the positive electricity of A′ B′, at the same time it attracts its negative electricity; but this negative fluid, accumulated on the plate A′ B′, in its turn reacts upon the plate A B, by attracting more of the positive fluid in it towards the surface nearest to the plate A′ B′; this increase of fluid on the plate A B produces a further action upon the plate A′ B′, and so on to an indefinite series of actions and reactions. The negative fluid accumulated in A′ B′ is called *disguised* electricity, for it cannot be detected by any ordinary means; it is retained or held there entirely by the attraction of the positive fluid in A B. The plate A′ B′ is called the *condensing plate*, and A B the *collecting plate*. An instrument constructed on this principle is called the *condensor*.

This principle of disguised electricity may be readily established by experiment.

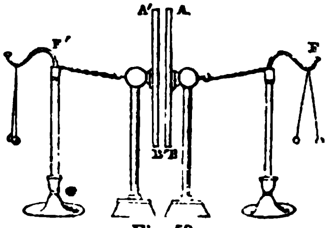


Fig. 59.

Exp. 1. Let the charged plate A B be connected by a chain with the insulated balls F, and the insulated plate A' B' with the insulated balls F'. First charge the plate A B, (say with positive electricity:) then the balls F will diverge; bring the plate A' B' near to A B: then the electricity in A' B' will be decomposed, and the balls will diverge. Touch A' B' with the finger so as to carry away its positive electricity set free: then the balls F' will immediately cease to diverge, and the balls F will have now only a very feeble divergence. The negative electricity in A' B' exists in a *disguised* state. Withdraw A B and A' B' from each other, taking care not to touch them: then immediately the balls diverge — those at F with positive electricity, and those at F' with negative. Bring the plates again near to each other, and the divergence of the balls F' again ceases, and that of F diminishes. The negative fluid of the plate A' B' is again disguised, and the positive fluid is partly withdrawn from the extremity F towards the extremity A B by the attraction of the negative fluid in the plate A' B'.

These facts enable us to give a satisfactory explanation of the principle of the condenser, of the electroscope, and of the Leyden jar.

The Condenser.

*27. The condenser, the principle of which has just been explained, is used to detect the presence of electricity where it is so very small as to require it to be collected and condensed before it will affect the electroscope.

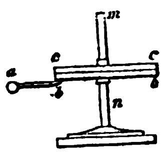


Fig. 60.

It consists of two disks of metal *b b* and *c c*, whose touching surfaces are polished and covered over with a thin coat of varnish or some non-conducting substance; the upper plate is the collector, and the lower one the condenser; the condenser stands on an insulating glass pillar *n*, and the collector has an insulating handle *m* attached to it, by which it may be lifted; a brass wire *a b* with a knob *a* is fixed to the under side of the condensing plate, for the purpose of connecting it with the ground.

The apparatus is thus used: Place the body whose electricity is to be examined in connection with the collector *c c;* touch the ball *a* with the finger, and after having taken it away, suddenly raise the collector by the glass handle *m*, and the electricity of the body under examination will have accumulated itself in the collector, and the opposite fluid will be found in the condenser; present the collector to any delicate electroscope or electrometer, and the accumulated electricity will be rendered apparent. The *rationale* of this process has already been explained.

28. ELECTROSCOPES AND ELECTROMETERS.

There are a great variety of electroscopes. For all ordinary purposes, the pith ball electroscope, represented in Fig. 3, or that described at page 214, is quite sufficient. But in pursuing many electrical inquiries, we require instruments of more delicacy, or of more durability.

In order to render electroscopic instruments more sensitive and more accurate, the two light bodies are suspended from a metal rod and enclosed in a glass bell, and the extremity of the rod (which is either a knob or a plate) is to be touched with the electrified substance. The light bodies, thus suspended, are either pith balls, as shown in Fig. 61,

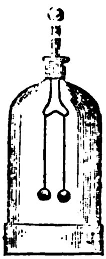


Fig. 61.

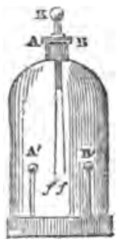


Fig. 62.

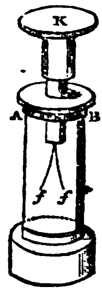


Fig. 63.

or two gold leaves, as in Bennet's electrometer, or *the gold leaf electrometer*, shown in Figs. 62 and 63. In Fig. 62, two knobs A′ and B′ are placed on each side of the gold leaves *f f*, so that when the leaves diverge too strongly, they impinge upon the knobs, and are thus discharged of their electricity; this contrivance prevents the leaves from being torn by adhering to the sides of the glass bell.

In order to insulate the electricity given to the cap or plate K, the metal rod carrying the gold leaves passes through a glass tube, which is cemented to a ferrule on the plate A B, closing the top of the glass

cover. (See Fig. 63.) This plate is screwed upon the glass cover, so that the leaves may be placed within the glass without injuring them. The gold leaves are attached to the lower extremity of the metal rod, simply by the adhesion of gum. Before using any electrometer, it is important that all its parts be perfectly dry, and that the surrounding air be warm and free from moisture.

To use the gold leaf electroscope: Bring an excited glass tube near to the cap K, and the gold leaves will diverge with positive electricity, because the positive fluid of the glass drives the positive fluid of the cap into the gold leaves. Excited sealing wax brought near to the cap will cause the leaves to collapse.

The following is the best method of using the simple gold leaf electrometer represented in Figs. 62 and 63; for it causes the gold leaves to be *permanently divergent*. Electrify a stick of sealing wax; hold the electrified wax very *near* to the cap K, without touching it; the gold leaves will diverge from each other on the principle of induction, with the same electricity as the wax, that is, with negative electricity; touch the cap with the finger, and the gold leaves instantly collapse; *first* remove the finger, *then* the electrified body and the gold leaves will remain *permanently* divergent, with an electricity opposite to that of the wax; that is, with positive electricity. Now bring an electrified glass tube near to the cap K, and the divergence of the leaves will be increased, because the glass, being positive, will drive more of the positive fluid into the gold leaves. After taking the glass rod away, bring electrified brown paper near the cap of the electroscope; the divergence of the gold leaves will be decreased, because the brown paper, being negative, will drive the negative fluid into the gold leaves, thereby neutralizing the positive fluid at first in them.

It should be observed that where the charge of the leaves is *temporary*, the electricity is the same as the excited body; but where the charge is *permanent*, as in the preceding case, the electricity is of an opposite kind.

Experiments with the Gold-leaf Electroscope.

Exp. 1. Strike the cap of the electroscope with a warm silk handkerchief; the leaves will diverge with negative electricity. Verify this by bringing an excited stick of sealing wax near to the cap.

Exp. 2. Excite a silk ribbon; bring it near to the cap of the electroscope; the leaves instantly diverge: excite a glass rod; bring it also near to the cap; the divergence of the leaves is diminished, thereby showing that the electricity of silk is negative.

Exp. 3. Rub a roll of brimstone with a piece of warm flannel, hold the excited brimstone near to the cap of the electroscope, touch the cap

with the finger; *first* take away the finger, and *then* the brimstone; the gold leaves will remain *permanently* divergent with positive electricity. Verify this by bringing an excited stick of sealing wax near to the cap.

Exp. 4. Place a tin vessel containing water on the cap K of the electroscope, (see Fig. 63;) drop a red hot cinder into the water; the leaves will instantly diverge. Here the escape of steam generates electricity.

The gold-leaf condensing electroscope, represented in Fig. 64, simply consists in the application of the condenser, described at page 240, to the gold leaf electroscope. Here $c\ c'$ is the collecting plate, with its glass handle m, placed upon the plate of the electroscope. In order to render this instrument more delicate, the glass bell of the ordinary electroscope is enclosed by a glass case, into which some chloride of calcium is put, with the view of absorbing any moisture which may be in the circumjacent air.

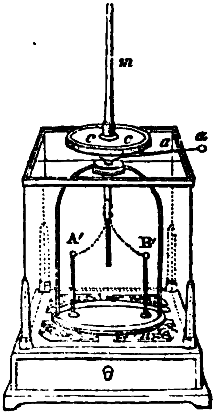


Fig. 64.

The degree of divergence of the gold leaves only gives us a rude idea of the intensity of the electricity with which an excited body is charged; for the divergence is not exactly in proportion to the intensity of the charge. These instruments, therefore, should be called *electroscopes* rather than *electrometers*. The name of electrometer should only be given to such instruments as Coulomb's balance, which afford us the means of exactly comparing the electrical intensities of any two bodies.

The needle electrometer, represented in Fig. 65, is a rod or needle balanced on a point, having pith balls fixed to its extremities.

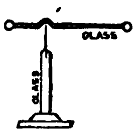


Fig. 65.

Coulomb's torsion electrometer. — For ordinary purposes, the instrument represented in Fig. 66 will be found exceedingly useful. A small disk of gilt paper C is attached to the end of a needle of gum lac or sealing wax; the needle is suspended by a thread of sealing wax K D, after the manner described at page 214, and placed within a glass jar or bottle, as shown in the figure; passing through the side of the jar, and on a level with the needle, is a brass wire, terminated with gilt balls A and B. To use the instrument, turn the knob K, if necessary, so as to bring the disk C in

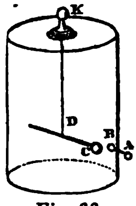


Fig. 66.

contact with the ball B; touch the ball A with the electrified body; then C, being electrified in the same way as B, will be repelled, and the angle of *torsion*, or twist, will indicate the force of repulsion, or, what is the same thing, the relative amount of electrical charge given to A. It will be observed that the force requisite to twist a thread is in proportion to the angle over which the needle is moved, so that the angle of deflection is a true measure of the electrical repulsion.

In comparing the intensity of two electrified surfaces, it is necessary that we should employ a *proof plane*, (which is a round piece of gilt paper fixed to the end of a rod of sealing wax or shell lac,) for the purpose of transferring the charges of electricity from the electrified surface to the ball A of the electrometer.

It is obvious that the torsion electrometer may be used, like the gold leaf electroscope, for ascertaining whether a body is positively or negatively electrified.

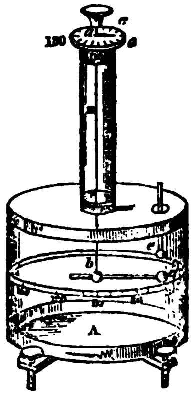


Fig. 67.

Fig. 67 represents the form usually given to the torsion electrometer, where the thread *b* B, supporting the needle *b d*, passes through a tube mounted on the glass jar A. The circumference of the jar is divided into degrees, the zero point being opposite to the ball to which the electricity is transferred, so that the angle through which the needle is repelled may be at once seen. The needle is usually supported by a fine thread of silver, about two feet long, fixed at the top of the tube to a brass piece *c*, which admits of being turned tightly round the cap, which is also of brass, and fixed to the tube itself.

By means of the torsion electrometer, Coulomb proved that the law of electrical attraction and repulsion, as influenced by distance, is the same as the law of gravitation; that is, inversely as the square of the distance. He also determined the law regulating the distribution of the electric fluid on the surfaces of conductors.

THE LEYDEN JAR AND ELECTRICAL BATTERY.

29. EXPERIMENTS WITH A SINGLE LEYDEN JAR.

Exp. 1. *To give an electrical shock.* — Charge the jar after the manner described at page 228; grasp the outside of the jar with one hand, and touch the knob of the jar with the other hand, and an electric shock will be felt. Care should be taken that the jar is not too strongly charged. Generally speaking, about half a dozen good sparks, transmitted to the knob of the jar, will be a sufficient charge for giving any person a shock.

A shock may be given to any number of persons at the same time. Let them form themselves into a ring, by taking hold of each other's hands; let the first person grasp the outside coating of a jar which has been charged, and then let the last person in the ring touch the knob of the jar; the whole of the persons forming the ring will instantaneously receive the shock. The number of the persons forming the ring does not appear to affect the intensity of the shock.

Exp. 2. *To show the striking distance of the spark at discharge.* — Touch the outside coating of a charged jar with one ball of the jointed discharging rod; gradually bring the other ball towards the knob of the jar; then, when they have come sufficiently near to each other, the electric spark will pass from one ball to the other with a snapping noise. The distance at which the discharge takes place depends upon the size of the jar and the intensity of the charge.

Exp. 3. *To show the manner in which a jar becomes charged.* — Place a common Leyden jar upon the insulated stool, and bring the knob within striking distance of the prime conductor; turn the machine, and it will be found that the jar cannot be charged when its outside coating is thus insulated: now bring your knuckle near the outside coating of the jar; then, for every spark of positive electricity which passes to the interior coating of the jar, a corresponding spark of positive electricity will pass from the outside coating to the knuckle. The positive electricity is driven off from the outside coating on the principle of induction, while the negative electricity is held in a disguised condition on the outside coating by the attraction of the positive electricity accumulated on the inside coating. Hence it appears, that when the inside coating is charged positively, the outside coating is charged negatively; and that when the jar is being discharged, the two opposite fluids rush to each other.

Exp. 4. *To charge the inside of a jar negatively.* — Place the jar upon the insulated stool; bring the outside coating of the jar within the striking distance of the spark of the prime conductor; turn the machine,

and at the same time, apply the knuckle to the knob of the jar; then, for every spark of positive electricity which passes to the outside coating, a corresponding spark of positive electricity passes from the inside coating to the knuckle, and thus the jar will become charged with negative electricity.

Exp. 5. To show the principle of disguised electricity in relation to the Leyden jar. — Let a jar be placed on the insulating stool, and let the ball D′, supported by a metal pillar, communicate with the outer coating of the jar. Suspend a ball of cork F, by a linen thread, midway between the knob D of the jar and the ball D′, communicating with the ground by a metal chain K. Charge the jar after the manner described in Exp. 3; then the ball will be attracted to D, and, owing to the contact, a certain portion of positive electricity will pass to the ground through K, and a certain portion of positive electricity will remain *disguised* on the inner coating; F, being thus restored to its natural state, will be attracted to the ball D′, owing to the negative electricity set free from the external surface of the jar: when F comes in contact with D′, a certain portion of electricity will, in like manner, pass off from the outer surface of the jar through the conductor K, and then a certain portion of negative electricity will remain *disguised* on the outer coating; F will then be again attracted to D; and so on. The ball F may continue to oscillate between the two knobs D and D′ for several hours; at the end of which time the two coatings will have lost their electricity by this succession of small discharges.

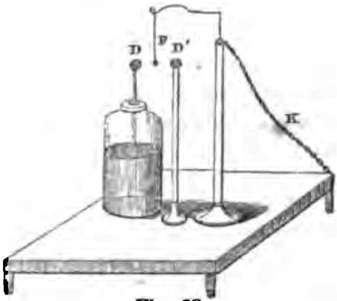


Fig. 68.

The apparatus represented in Fig. 69 is intended to illustrate the same principle. The insulated balls on F are in connection with the inner coating, and those on F′ are in connection with the outer coating. Charge the jar after the manner described in Exp. 3; then the balls F will diverge with positive electricity, and the negative electricity will be held in a *disguised* state on the outer coating. Touch the knob D, and the balls F will collapse, while the

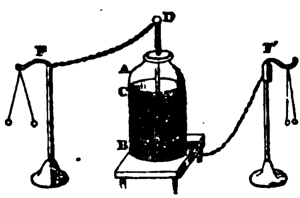


Fig. 69.

balls F′ will diverge; the positive electricity is now in a *disguised* state, while the negative is free; and so on, until all the fluid is taken from the jar.

Exp. 6. *To make a jar out of a common vial.* — Fit a cork to the vial, and pass a wire through it, reaching nearly to the bottom of the vial; put a knob on the outer extremity of the wire; half fill the vial with water, and, after carefully drying the outside, put the cork with its wire in its place; grasp the outside of the vial with one hand, and, after having taken a few sparks from the prime conductor to the knob, touch the knob with the other hand, and you will receive an electric shock.

Here the hand answers the purpose of the external coating of the Leyden jar, and the water that of the internal coating.

Exp. 7. *The electrical sportsman.* — This consists of a jar J connected with the figure D of a sportsman, who is supposed to be in the act of shooting some birds flying over the ball A. The knobs A and B are connected with the inner coating of the jar, and the knob C at the extremity of the sportsman's gun is connected by a wire going down the figure with the outer coating. The figure admits of being turned round upon a pin D at its foot. Some light substances, cut in the shape of birds, are suspended by cotton threads from the ball A. Charge the jar; the birds appear to fly, owing to their mutual repulsion; turn the sportsman round until you bring the muzzle C of his gun within striking distance of the spark; at the moment the snap and spark of discharge takes place, the pith birds appear to fall down as if they were shot.

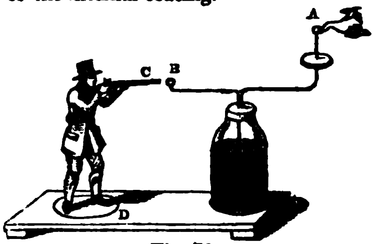


Fig. 70.

Exp. 8. *To ignite cotton.* — Tie a bit of cotton, mixed with a little powdered resin, on one of the knobs of the jointed discharger; place the other knob in contact with the outer coating of a charged jar; bring the knob, covered with the cotton, within striking distance of the knob of the jar: and the spark will ignite the cotton.

Exp. 9. *To perforate a card.* — Hold a dry piece of card paper in contact with one of the knobs of the jointed discharger; discharge the jar through the card paper, and it will be found to be perforated by the passage of the spark.

Discharge the jar through three or four pieces of card paper, or through about a dozen sheets of writing paper.

The hole in the paper will be always found to be burred equally on each side, as if the electric fluid had come from the middle of the card.

Exp. 10. *The magic picture.* — This is simply a pane of glass placed in a frame, and covered on both sides with tin foil within a few inches of the edges. It answers the same purpose as the Leyden jar. Charge one side of the plate after the manner described in Exp. 3; discharge the plate in the usual way.

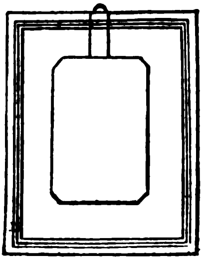


Fig. 71.

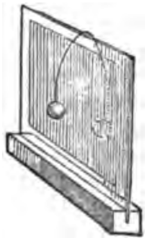


Fig. 72.

Exp. 11. *The electric pendulum.* — Make an electric pendulum of wire, with pith balls at the end of it, as represented in Fig. 72. Balance the pendulum on the edge of a charged plate of glass; the pendulum will vibrate; the balls alternately strike the plate.

ELECTRICAL BATTERIES.

30. An electrical battery is formed when several jars are united together, by establishing a metallic connection between all their inner coatings, and a similar connection between all their outer coatings. The jars are placed in a wooden box lined with tin foil, upon which the jars stand, and which forms the connection between all the outer coatings; the inner coatings communicate together by means of metal rods, which connect the

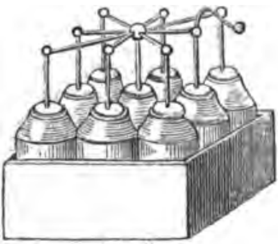


Fig. 73.

various knobs of the jars together. The battery is usually discharged by means of a chain, which has one of its extremities fixed to the tin foil of the case, and the other extremity attached to the knob of a discharging rod.

It always requires time, even with a good machine, to charge a large battery. In order to accelerate the operation, a peculiar contrivance, represented by Fig. 74, has been adopted, called *charging by cascade*. Here each jar of the battery is placed upon an insulating stool, and the knob of each is connected by means of a chain C with the outer coating of the preceding one; the knob D′ of the first jar A^1 is connected with the prime conductor, and the outer coating of the last A^4 is connected with the ground by means of the chain D. When the machine is worked, the positive electricity from the outer coating of A^1, in place of being driven away into the ground, serves to charge A^2, by passing into its inner coating; in like manner, the positive electricity driven off from the outer coating of A^2 serves to charge A^3; and so on, until the positive electricity is carried away from the outer coating of the last jar into the ground by means of the chain D.

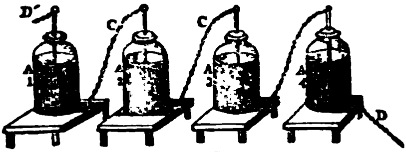


Fig. 74.

The battery is discharged by connecting D with D′.

DISCHARGING ELECTROMETERS.

81. In these electrometers, the intensity of the electricity is measured by the length of the spark at the instant of discharge.

Lane's discharging electrometer. — This is an ordinary Leyden jar, having an arm *c d e* attached to the conducting wire *a b*; the horizontal part *c d* is of glass, coated over with shell-lac; the vertical part *d e* is a brass rod, having a ring *e*, in which the graduated wire *m o* slides, and terminating in a knob *o*; the distance between the knobs *o* and *b*, and consequently the length of the spark, can thus be measured. To use the jar, connect the extremity *m* of the sliding wire, by means of a chain, with the

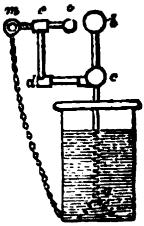


Fig. 75.

outer coating of the jar, and then adjust the distance between the knobs *o* and *b* to suit the amount of charge which you wish to give to the jar. Bring the knob *b* near to the prime conductor, and continue to work the machine until the discharge takes place between the knobs *b* and *o*. If the knobs *b* and *o* are placed very near together, the intervening space will be penetrated by the spark when only a small charge has been given to the jar; but if the distance between them be increased, then a more powerful charge may be given before the spontaneous discharge takes place. If the same distance between the balls *o* and *b* be retained, then the discharge will always take place when the same quantity of electricity has been transmitted to the jar. This jar may be used to test the relative powers of two electrical machines; in order to do this, you plase the balls *o* and *b* at a certain convenient distance from each other: then that machine will be most powerful which causes the jar to be discharged with the least number of turns of the handle.

Cuthbertson's discharging electrometers. — This apparatus, represented in Fig. 76, effects the discharge of itself when the jar or battery has arrived at the limit of its charge.

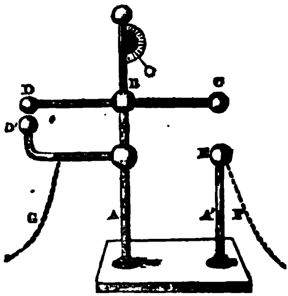


Fig. 76.

An insulating support A B carries a metal rod D C, turning on a centre at B like the two arms of a balance. This metal rod is connected with the inner coating of the jar, or battery, and also with a quadrant electrometer, as shown in the figure. Below the knob C, at a sufficient distance to prevent discharge, is another knob E, which communicates with the outer coating by means of the chain F; nearly in contact with the knob D is another knob D′, placed at the extremity of a metal rod, which is fixed to the same support as the rod D C, and, being in metallic communication with it, is also connected with the inner coating of the jar or battery. When the jar has become sufficiently charged, the knob D is repelled from the knob D′, and the knob C is thereby brought nearer to the knob E in connection with the outer coating; and when this distance is within the distance at which explosion takes place, the jar or battery is discharged.

Fig. 77 represents a slightly different form of this apparatus, where L is a sliding ball, which enables the operator to give a more perfect adjustment to the action of the apparatus.

The balance electrometer simply consists of a common balance beam, with a scale hung on one side for holding weights, and a gilt piece

of wood hung on the other for the purpose of being applied to the surface of an electrified body. The weight necessary for overcoming the attraction of the electrified surface on the gilt piece of wood is taken as the relative measure of the intensity of the electricity on the surface of the electrified body.

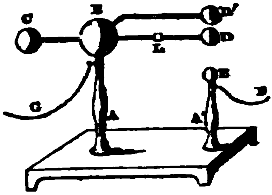


Fig. 77.

MECHANICAL EFFECTS OF ELECTRIC DISCHARGES.

32. The following experiments may be performed with a single jar; but the effects, in most cases, will be more striking when a battery is used.

Exp. 1. *The thunder house.* — This apparatus illustrates the use of metallic rods as a protection to buildings from the effects of lightning, and also shows the use of *pointed* rods as tranquil conductors of electricity. The conductor C D is broken at A and B by two little square slips of wood having conducting wires passing through them, and which may be inserted in their places, either with the conducting wire broken, as at B in the figure, or with the conducting wire unbroken, as at A; the ball C may be screwed off the wire, and then it is terminated by a point.

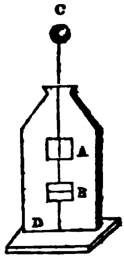


Fig. 78

To use the apparatus, first let the ball C be screwed on the top of the conducting wire, and let the square slips be placed as in the figure; connect the extremity D of the conducting wire with the outer coating of a charged jar; place one knob of the jointed discharger within striking distance of the ball C, and gradually bring the other knob of the discharger within striking distance of the knob of the jar; the disruptive effect of the charge will throw out the slip B, while A remains in its place.

Perform the same experiment when the ball C is taken off: the charge will pass quietly through the point, and both slips will remain in their place.

Exp. 2. *The electric bomb.* — A cavity is made in a block of wood C, and closed by a cork D; two wires A and B pass into this cavity, having their points about a quarter of an inch asunder. Now connect the knob B with the exterior coating of a jar or battery; and with the knob of the discharging rod in contact with the knob A, discharge the jar or battery, and the cork will be forcibly projected from the cavity.

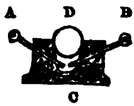


Fig. 79.

Fill up the cavity with sand; transmit a charge through it; and the passage of the spark will disperse the sand in all directions.

Exp. 3. *Dispersion of water.* — Transmit a strong charge through the fluid: it will be scattered in all directions.

Exp. 4. *To perforate glass.* — Fill a vial A (see Fig. 80) with oil; close it with a cork, through which a wire B passes, having its lower end so bent that its point shall touch the inner surface of the vial. Connect the extremity B with the outside coating of a charged jar; place the knob C of the jointed discharger opposite to the point, then discharge the jar, and the spark in its passage through the glass will make a hole.

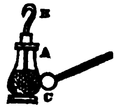


Fig. 80.

This experiment may also be performed by suspending the vial from the prime conductor of a powerful machine, and taking the spark from the point by bringing a brass ball opposite to it.

Exp. 5. *To break wood and glass.* — Transmit a strong charge through a stick of wood, in the direction of its fibres, about half an inch thick: the wood will be split.

Discharge a jar or battery through a plate of window glass, after the manner described at page 252, Exp. 9: the glass will be broken.

Exp. 6. *To rupture substances which are imperfect conductors of electricity.* — Place several dry cards together between the knobs of the universal discharger; pass a strong charge through them, and the spark will pierce a hole through them. The cards will have a peculiar sulphurous odor, like that which is perceived in places after they have been struck by lightning.

Thin pieces of wood may be ruptured in the same manner.

Place a piece of dry writing paper on the stage of the universal discharger, lay its knobs on the paper, at the distance of an inch and a half from each other; then transmit the charge, and the passage of the spark, if sufficiently strong, will tear the paper asunder.

Lay a piece of perforated tin foil between two panes of glass; fix them tightly together, and transmit a strong charge through the tin foil: the panes of glass will be split by the discharge.

Exp. 7. *An electrical thermometer, sometimes called a thermo-electroscope.* — This piece of apparatus, represented in Fig. 81, is intended to show the momentary expansion of the air produced by the heat of the spark in its passage through the air. A is an air-tight tube communicating with a small tube B which is open at the top; *a* and *b* are two knobs attached to the extremities of wires passing out of the tube; a colored liquid below the level of the knob *b* stands at the same height in the two tubes. When a charge or

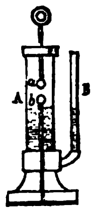


Fig. 81.

spark passes from *a* to *b*, the air in A expands by the heat developed by the passage of the spark; the liquid in A will therefore fall, while that in B will rise. The strength of the electric charge is indicated by the amount of expansion.

HEATING EFFECTS OF ELECTRIC DISCHARGES.

33. *Exp.* 1. *Ignition of resin upon water.* — Sprinkle some powdered resin on the surface of water contained in a cup; connect the outer coating of a charged jar, by means of a chain, with the water in the cup; discharge the jar, by causing the spark to pass through the resin, which will instantly ignite.

Various other substances may be ignited in a similar manner.

Exp. 2. Place a skein of cotton, impregnated with any resinous powder, on the stage of the universal discharger; pass the spark through the cotton, and it will be ignited. This is another way of performing Exp. 8, explained at page 252.

Exp. 3. *Explosion of gunpowder.* — The igniting power of an electric spark is increased by passing the charge through a damp conductor. In this way we are enabled to fire gunpowder, which cannot be ignited by the spark under ordinary circumstances; place some fine gunpowder in the wooden cup C, (Fig. 79;) carry the fluid for about six inches along a damp thread attached to that arm of the discharger which is connected with the outer coating of the jar: then the passage of the spark from the end of one wire to the end of the other will ignite the powder.

Here the moist thread, being a somewhat imperfect conductor, retards the passage of the electric fluid, and thereby causes the discharge to take place with less rapidity than it would otherwise do.

Exp. 4. *A fine wire heated, fused, and burned.* — Stretch a few inches of very fine harpsichord wire between the ends of the universal discharger, (see Fig. 33;) send a good charge through the wire, and it will be either rendered incandescent, or it will be fused. The length of wire which may be fused depends upon the size of the battery and the intensity of the charge. A battery composed of half a dozen ordinary jars, and fully charged by a good machine, will readily fuse about six inches of fine harpsichord wire.

The heating effects of electrical charges on different metals depend on their conducting powers; thus platinum and iron, which are bad conductors of electricity, become more powerfully heated by the passage of an electrical charge than gold and copper, which are good conductors.

The thermo-electroscope, represented by Fig. 82, depends upon this principle. C D A B has the form of a differential thermometer; a platinum wire passes through the ball C, and is hermetically sealed to it. When an electric charge is transmitted through the platinum wire, it becomes heated, and this causes the air in the ball C to expand, which is instantly made manifest by the rise of the liquid in the tube A B. The graduated scale on A B gives the relative heating powers of different charges. This instrument is best adapted to the measurement of the heating power of voltaic electricity.

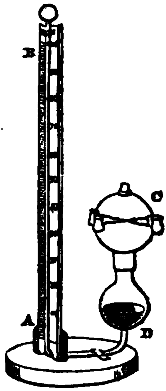


Fig. 82.

Exp. 5. *Ignition and fusion of gold leaf.* — Plac a strip of gold leaf between two pieces of dry paper; lay them on the table of the universal discharger; pass a good charge through the gold leaf, and it will be burnt. Both pieces of paper will be covered with a purple strip of oxide of gold; the strip has a grayish tinge when the gold leaf contains a portion of silver.

Exp. 6. Place a small bit of gold leaf between two pieces of window glass; proceed as in the last experiment, and the gold will be fused into the glass.

Exp. 7. *Ignition of gilt thread.* — Stretch a gilt thread of silk between the extremities of the universal discharger; send a charge through the thread, and the electric fluid, in its passage, will burn the gilding, and the silk will remain uninjured.

PHYSIOLOGICAL EFFECTS OF ELECTRIC DISCHARGES.

34. The sensation of a spider's web being drawn over the face, and the peculiar phosphoric odor attending the transmission of electricity, are amongst the most ordinary physiological effects of electricity. When a strong electrical charge passes through the body, it is accompanied by a shuddering sensation and a sudden contraction of the muscles, which is called the *electric shock*. (See Exp. 4, page 231.) The discharge from a single jar is sufficient to destroy the life of small animals; and the discharge of a powerful battery through the head of a large animal is enough to kill it.

Exp. 1. In taking a shock from a jar, interpose in some part of the circuit a damp rope: then, instead of the usual shock, there will be merely a tingling sensation produced at the tips of the fingers.

Exp. 2. Place the head of a live mouse between the wires of the universal discharger; send a strong shock through it, and the mouse will be instantly killed.

MAGNETIC EFFECTS OF ELECTRIC DISCHARGES.

35. *Exp.* 1. Place a small sewing needle in a helix or spiral formed of copper wire, *a b*, (Fig. 83,) covered over with silk; place the ends of the helix in contact with the arms of the universal discharger; transmit a strong charge through the wire, and the needle will be rendered magnetic. The end of the needle which lies to the right of the electric current will be a north pole, and the opposite end a south pole.

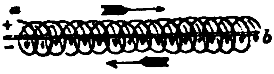


Fig. 83.

Exp. 2. Reverse the direction of the needle of the last experiment; transmit two or more charges of electricity through the helix, and the poles of the needle will be reversed.

The magnetic effects of common electricity are very feeble as compared with those of voltaic electricity. The explanation of these phenomena will be given in connection with the subject of galvanism.

CHEMICAL EFFECTS OF ELECTRIC DISCHARGES.

36. The chemical effects of the ordinary electric currents, like the magnetic effects, are comparatively feeble. The following experiments, however, show that ordinary electricity really possesses a decomposing influence.

Exp. 1. Place two pieces of tin foil *t t* on a dry pane of glass G G; on these pieces of tin foil lay platinum wires, bent in the manner shown in Fig. 84, so that there shall be a small space between the two points at *k*, where they touch the glass, and

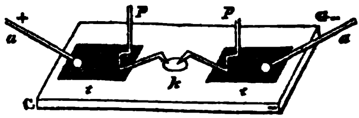


Fig. 84.

where the body which is to be decomposed is placed. Lay the glass G G on the table of the universal discharger; place its two knobs on the tin foils, and connect one of them by a chain and a moist thread with the prime conductor of the machine, and the other with the insulated cushion. Place a drop of a solution of iodine of potassium at *k*, between the platinum points; turn the machine, and after a short time the iodine will be deposited at the positive wire, and the metallic potassium at the negative wire. Perform the same experiment with a drop of a solution of sulphate of copper, and so on.

These experiments may be performed with more delicacy by using blotting paper saturated with the solutions; thus paper dipped in a solution of iodine in alcohol will readily give a blue tinge of iodine on the paper in contact with the positive wire.

The decomposition of water by common electricity was first shown by Wollaston.

Sparks discharged for a length of time through the air of a closed receiver cause the two gases in the air to combine and form nitric acid; in this way, no doubt, nitric acid is formed in the atmosphere by lightning.

Exp. 2. Place a fine metal point in connection with the prime conductor of the machine; work the machine for some time, and then bring the metal point in contact with the tongue: a faint acid taste is felt; whereas the negative electricity will produce an alkaline taste.

DISTRIBUTION OF ELECTRICITY.

37. The electric fluid arranges itself upon the surfaces of conductors.

Exp. 1. A is an electrified metal ball, suspended by a silk thread; B and C are two hollow metal hemispheres, which exactly envelop the

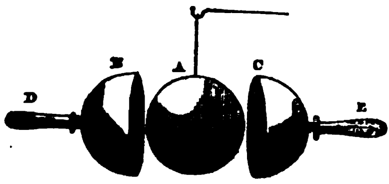


Fig. 85.

sphere; when they are removed from the sphere, then not the slightest trace of electricity remains upon it, while the outer surfaces of the hemi-

spheres contain all the electricity which was at first in A. This may be proved by means of the electroscope.

The Proof Plane.

To show in a more complete manner the superficial distribution of electricity, a small piece of apparatus, called a *proof plane*, is usually employed. This apparatus is represented in Fig. 86, where C is a small disk of gilt paper, fixed at the end of a stick of gum lac A B. In using this instrument, a point of the electrified surface is touched by the proof plane, which being carried to the torsion electrometer, the intensity of the electricity at the point touched by the proof plane is indicated by the deflection of the needle.

Fig. 86.

Exp. 2. A is a conical muslin bag, fixed to an insulated metal ring, forming something like a butterfly net; B and C are silk threads attached to the apex of the cone, one on the outside and the other on the inside, by which the cone may be turned outside in. Let the cone be charged with electricity by means of a carrier ball; test the electricity of the inside and outside surfaces by means of the proof plane; then it will be found that, while the outside surface is charged with electricity, the inside surface is entirely free from it. Turn the cone outside in, and test the surfaces as before; the surface which is now outside will contain all the electricity, and that which is now inside will be entirely free from it.

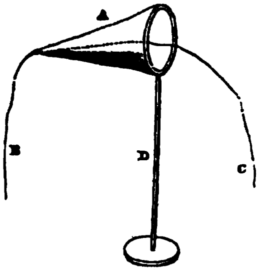


Fig. 87.

These experiments clearly show that the electricity distributes itself upon the exterior surface of a conducting body, but not on the interior surface.

The following experiment, first given by Faraday, establishes the same principle, as well as an important law relative to the induction of electricity: * —

* By applying his theoretical ideas to other and different phenomena of statical electricity, Faraday is led to admit that the tendency of electricity to distribute itself on the surface of conducting bodies is more apparent than real, and that the experiments which prove that there is not, in fact, any free electricity except at their surface, are easily explained in another manner. No electric charge, according to this theory, can be manifested in the inte-

An insulated electrified ball A is sustained in the interior of a series of jars, placed the one within the other, and separated from each other by plates of gum lac, as shown in Fig. 88; the outer jar B communicates with a gold leaf electroscope C, the leaves of which L diverge the moment the electrified ball A is introduced. Here induction takes place from jar to jar, until at last the outer surface of the jar B becomes electrified.

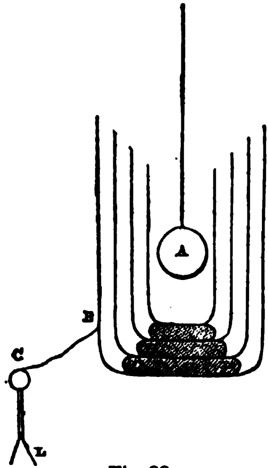


Fig. 88.

Upon testing the electricity on the surface of the jars by means of the proof plane, it will be found, while the outer surfaces of the jars all contain electricity the inner surfaces are entirely free from it.

While the gold leaves L are divergent, let the electrified ball A touch the side of the inner jar, and it of course transmits its electricity to the jar, and the gold leaves neither diverge more nor less than before. This experiment proves that the electricity possessed by the ball is exactly equal in quantity and in power to that which it develops by induction.

rior of a body, on account of the opposite directions of the electricities in each of the interior particles; whence the resulting effect is null; whilst the induction exercised by exterior bodies renders the electricity sensible on the surface. From this manner of regarding it, electricity must show itself only on the surface of a conducting envelop, whatever be its conductibility or the insulating property of the substance placed within. Faraday, in fact, demonstrated this by strongly electrizing oil of turpentine placed in a metal vessel. There was no apparent electricity, except on the exterior surface of the vessel. He also constructed a cubical chamber, twelve feet square, the wooden sides of which were covered outside with tin foil; he insulated it; then, after having introduced into it electroscopes and other objects, he electrized the interior air with a strong machine. No trace of electricity was manifested within; whilst considerable sparks and luminous brushes darted off in all directions from the exterior surface. While these experiments complete those of Coulomb, in which he operated only upon conducting bodies, they render the explanation that was given rather improbable, since it was based upon the free propagation of electricity in the conducting mass; whence it followed that this electricity distributed itself entirely on the surface. When once the phenomenon has occurred in the same manner with insulating bodies placed interiorly, this explanation is not tenable.

With regard to the influence of form upon the quantity of electricity

The intensity of the electricity upon a conducting body depends upon the extent of that surface.

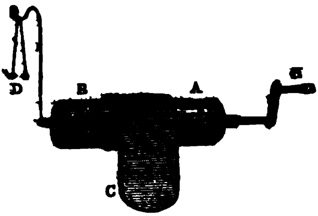


Fig. 89.

Exp. 3. A B is an insulated metallic roller, which may be turned by the insulated handle H; D is a pith ball electroscope; C is a metallic ribbon coiled upon the roller. Let the roller be charged with electricity, then the balls D will diverge from each other, indicating the intensity of the charge; let the metallic ribbon be unrolled, drawing it by means of a silk thread attached to the extremity C; then the balls D will approach each other,

accumulated at the surface of bodies not spherical, it would always depend, according to Faraday's theory, upon some points of the surface being exposed to a greater amount of inductive forces than others. Thus the extremities of a cylinder, or of an elongated ellipsoid, would be more strongly electrized than the rest of the surface, because there go from them a greater number of filaments of polarized particles, establishing with surrounding conductors the communication necessary for induction. A point is far superior in this respect; for it is the centre whence emanate in all directions the lines of inductive force, which, for example, when a ball is in question, are found distributed over a greater extent, and do not set out from a single point only, but equally from all points of its surface.

In the theory that we have been explaining, the mutual repulsion of bodies charged with the same electricity is only apparent; it is called into existence because there is no electricity on the nearer surfaces, and because each of the bodies is attracted in opposite directions by the surrounding bodies, upon which induction determines an electrical state dissimilar to their own. We may even prove, by means of the proof plane, that the two gold leaves of an electroscope, when they are diverging, have no electricity on their interior surface, whilst they are strongly electrized exteriorly, however thin they may be in other respects. Repulsion is also explained by attributing it to the attraction exercised upon each of the gold leaves by the contrary electricity, developed by induction, in the strata of air in contact with their exterior surface. This mode of action of the air is much more natural and more probable than that in which it is regarded as determining repulsion by the greater pressure from within outwards, than inwards from without, which it exercises upon electrized bodies. However, the experiments which show that repulsion takes place *in vacuo* as well as air, would seem to be equally contrary to these two explanations, except that, in the former, we admit the effect by induction of the ambient bodies, even when they are placed at a great distance.

owing to the electricity having become spread over a greater extent of surface; now let the ribbon be rolled up, by the insulated handle H, and the pith balls will again diverge from each other.

Exp. 4. *To show that electricity accumulates itself towards the extremities of an insulated conductor.* — Touch the different parts of the electrified conductor with the proof plane, and test the intensity of the electricity in each case by means of the torsion electrometer, and it will be found that those parts of the conductor which are farthest from the middle have the greatest intensity. Hence the tendency of the electric fluid to escape from pointed extremities. These effects apparently arise from the mutual repulsion of the particles of the fluid.

ATMOSPHERIC ELECTRICITY.

THE IDENTITY OF ELECTRICITY AND LIGHTNING.

38. The honor of this discovery belongs to Franklin. In a letter to a friend he gives the following account of the origin of the conception which conducted him to the great discovery: "Your question, how I came first to think of proposing the experiment of drawing down the lightning in order to ascertain its sameness with the electric fluid, I cannot better answer than by giving you an extract from the minutes I used to keep of the experiments I made, with memorandums of such as I purposed to make, the reasons for making them, and the observations that arose upon them, from which minutes my letters were afterwards drawn. By this extract you will see that the thought was not so much an out of the way one, but that it might have occurred to an electrician. 'Nov. 1749. Electric fluid agrees with lightning in these particulars: 1. Giving light; 2. Color of the light; 3. Crooked direction; 4. Swift motion; 5. Being conducted by metals; 6. Crack or noise in exploding; 7. Subsisting in water or ice; 8. Rending bodies it passes through; 9. Destroying animals; 10. Melting metals; 11. Firing inflammable substances; 12. Sulphureous smell. The electric fluid is attracted by points. We do not know whether this property is in lightning, but since they agree in all the particulars in

which we can already compare them, is it not probable they agree likewise in this? Let the experiment be made.'"

This letter will always be read with interest, affording, as it does, one of the most admirable examples of inductive reasoning.

Franklin made the experiment in the following manner. He made a kite with points fixed to it, with the view of drawing electricity from the clouds. In order to insulate the electricity that might pass down the hempen cord, which is a partial conductor of electricity, he attached a silk cord to its extremity, where he placed a key, from which he expected to obtain sparks of electricity. Afraid of being laughed at, should his experiment fail, he took his little boy with him, to make it appear as if he were going to assist the boy in flying his kite. Franklin and his little boy having raised their electrical kite in the air, they waited a long time before any indications of electricity could be seen. At length a thunder cloud passed over the kite; the electric fluid passed from the cloud to the points fixed on the kite, and descended the hempen cord, the fibres of which stood erect by electrical repulsion; Franklin then applied his knuckle to the key, and received the electric spark.

What must have been the ecstasies of his soul at that moment! He had made one of the most brilliant discoveries in the whole range of physical science! he had discovered the identity of lightning and electricity!

He afterwards charged Leyden jars with lightning, and made other experiments, similar to those usually performed with electrical machines. He also introduced lightning conductors, or pointed rods, for the protection of buildings from the effects of lightning. (See Exp. 1, page 256.)

The picture of Franklin and his little boy flying the kite which first drew lightning from the clouds, will be regarded with interest to the latest ages of the world.

About the same time, acting under Franklin's suggestion, Dalibard erected an insulated pointed rod, 40 feet high, and thereby succeeded in obtaining sparks from the clouds.

Fig. 90.

ELECTRICITY IN THE AIR.

39. Electricity is always found in the air, but it varies both in kind and in quantity. It is generally positive when the air is clear and serene, and negative when it is humid and cloudy. The intensity of electrical phenomena is usually greatest in the higher strata of the atmosphere: it is also stronger in winter, especially during frosty weather, than it is in summer, and when the air is calm than when it is boisterous. When the wind blows from the north, the drops of rain are generally positive, and when it blows from the south, they are generally negative. The earth is always in a contrary state of electricity to that of the higher strata of the atmosphere; and hence the atmosphere, at the height of a few feet above the surface, is always in a neutral state. The aerial

electricity attains a maximum and minimum condition twice every day; its intensity is least during the night; it increases after sunrise, or during the fall of dew, and attains its maximum condition a few hours after sunrise: from that time it gradually decreases until a few hours before sunset, when it reaches its second minimum condition; after sunset it rises rapidly, especially during the fall of dew, and attains its second maximum condition a few hours after sunset.

ELECTROMETEORS.

40. The most common electrometeors are *thunder storms, sheet lightning, the aurora borealis, waterspouts, whirlwinds,* and the luminous appearance of pointed conductors. The commonest and grandest of these electrical phenomena are thunder and lightning.

THE AURORA BOREALIS, OR NORTHERN LIGHTS.

41. In the higher regions of the atmosphere, where the air is very much attenuated, the flashes of electric light give

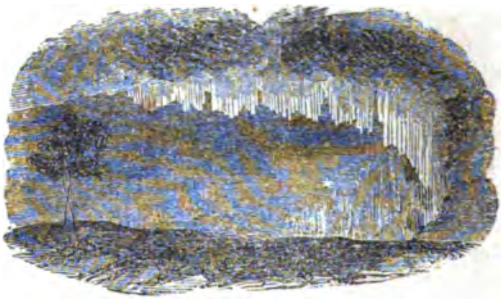


Fig. 91.

rise to the well-known phenomenon of the aurora borealis, or northern lights. (See Exp. 2, page 238.) This meteor is seen most brilliantly towards the arctic regions. Fig. 91 repre-

sents the appearance which it presents at its commencement, where streams of electric light appear to move from the northern parts of the horizon towards the magnetic zenith. Sometimes, even with us, it assumes the form of a magnificent luminous bow, spanning the horizon for thirty or forty degrees.

Figs. 92 and 93 represent some of the appearances of the

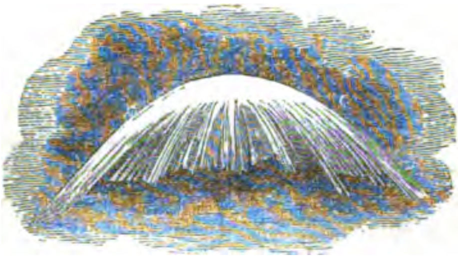


Fig. 92.

aurora borealis at the north arctic zone, as given by M. Lottin, an officer of the French navy.

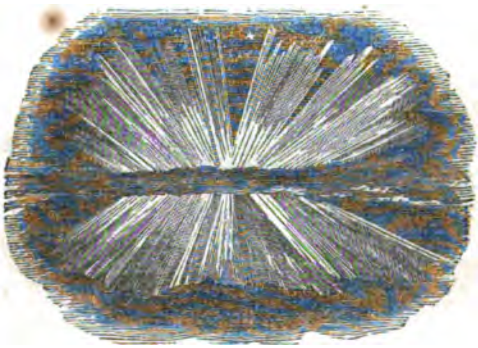


Fig. 93.

Fig. 94 represents a remarkable appearance of the aurora borealis, which was seen over every part of Europe. This was observed and described by Mairan in the year 1726.

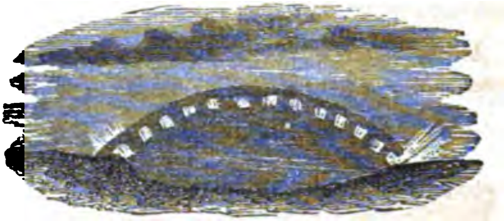


Fig. 94.

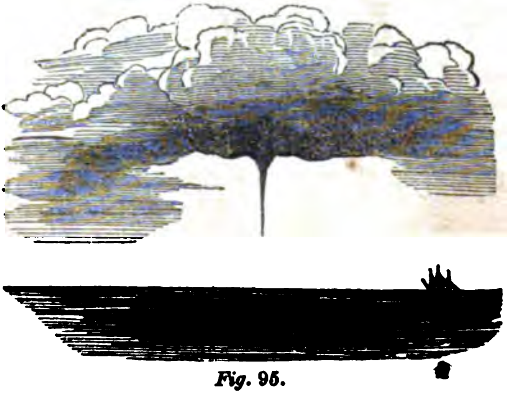


Fig. 95.

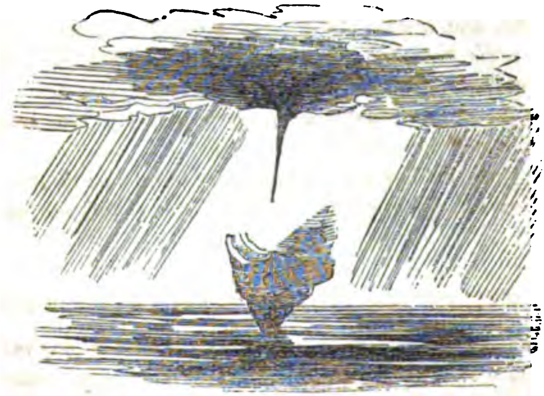


Fig. 96.

WATERSPOUTS.

42. At the commencement of this wonderful and terrific phenomenon, the watery vapor in the clouds appears to de-

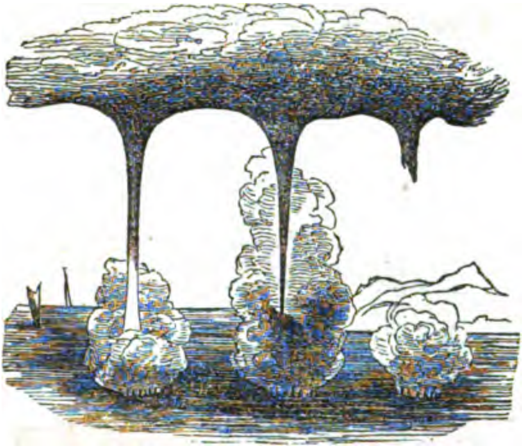


Fig. 97.

scend in the form of a cone, while the ocean beneath becomes agitated, as shown in Fig. 95; the apex of the cone continues to descend, and, after a little time, a cloud of watery vapor rises from the ocean towards it, as shown in Fig. 96. This goes on until the two streams of watery vapor join each other and form a complete waterspout, or, it may be, form two or more waterspouts, as shown in Fig. 97.

These remarkable phenomena appear to be due to the different electrical conditions of the cloud above and the ocean beneath.

DIFFERENT MODES OF GENERATING ELECTRICITY.

43. Besides friction, there are various modes of generating electricity. The following are amongst the most remarkable: —

ELECTRICITY GENERATED BY THE FRICTION OF HIGH PRESSURE STEAM.

The friction of high pressure steam on the metallic pipes, &c., through which it is made to pass, has recently been found to develop large quantities of electricity.

A very powerful electrical machine has been constructed on this principle by Mr. Armstrong of Newcastle, and called by him the Hydro-electric machine.

HYDRO-ELECTRIC MACHINE.

44. This machine is represented in Figs. 98 and 99. A is a strong steam boiler, cased in wood to reduce the radiation of heat, standing on

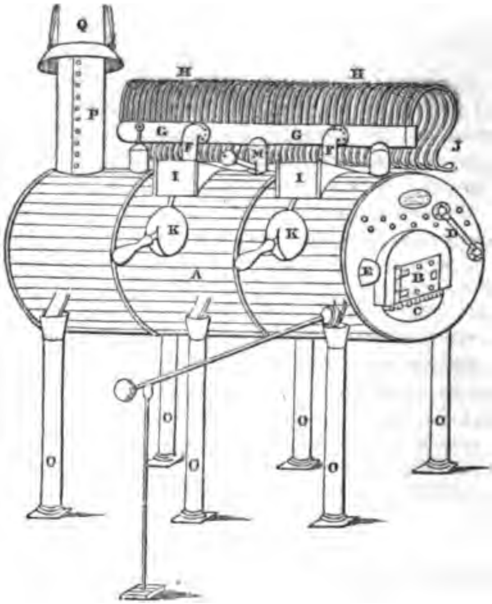


Fig. 98.

six glass pillars O; B the furnace, and C the ash pit, formed in the under part of the boiler; P Q the chimney; D is a water gauge, and E

the feed valve; F F two tubes leading from the valves I I to the large tubes G G; H H are a series of bent iron tubes, proceeding from the pipes G G, and terminating in jets J, which may be opened or closed, by means of levers placed at K K; M is the safety valve.

Fig. 99 represents a zinc case, provided with four rows of brass points, which are placed in front of the rows of the jets J, (Fig. 98,) in order to

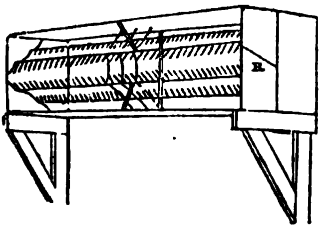


Fig. 99

attract the electricity from the steam vapor projected upon them: when long sparks are required, this case, with its points, is placed at the distance of about one foot from the jets; and, on the contrary, when a large quantity of electricity is required, the case is brought within a few inches of the jets. With a view of augmenting the development of the electricity, the inner surfaces of the jets are lined with wood, forming a bent channel for the passage of the steam.

In this machine, we may regard the particles of water as serving the purpose of the glass plate of a common electrical machine; the wooden lining of jets as the rubber; and the steam as the rubbing power.

The electricity generated by this engine is more remarkable for its enormous quantity than for its high intensity. The engine erected by Mr. Armstrong, at the Polytechnic Institution, gave sparks from twelve to fourteen inches in length, and charged a battery, containing 80 feet of coated glass, in ten seconds. The dense sparks, which pass from the boiler to any large ball conductor, follow each other in such a rapid succession, as to give to them somewhat of the character of a galvanic flame.

ELECTRICITY DEVELOPED BY CONTACT.

45. When two different metals are brought into contact, electricity is developed; the positive fluid being attached to the one metal, and the negative fluid to the other. C and Z are two plates of copper and zinc, having the insulating handles A and B. Let them be brought in contact, and

then separated, taking care to hold them by the insulating handles, and to move them towards and from each other, so that no friction shall take place in forming or breaking the contact; then the zinc plate will be charged with positive electricity, and the copper plate with negative electricity; which may be proved by bringing the plates in contact with the connecting plate of the condensing electroscope. (See Fig. 64.)

This constitutes the fundamental experiment of voltaic electricity.

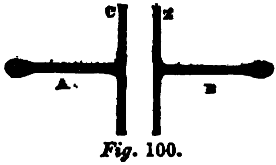


Fig. 100.

Fig. 101.

Deluc's Dry Piles.

On this principle Deluc constructed his electric pile, which consisted of a series of disks of copper and zinc paper, laid the one upon the other, with their paper sides together. A pile containing about 1000 pairs of these disks exhibits a decided evidence of electrical attraction and repulsion when a connection is formed between the extreme plates. What is remarkable in these dry piles is, that they will remain with undiminished action for years, without being at all interfered with.

Zamboni's Electrical Perpetual Motion.

This beautiful piece of apparatus is formed by placing two of Deluc's piles, (Fig. 102,) each containing about 1000 pairs of plates, within about two inches of each other, so that their unlike poles may be brought near each other at the top and bottom. The upper extremities of the piles terminate in two metal knobs, C and D, and the lower extremities are connected by a strip of copper, so that while one knob C is positive, the other knob D is negative. P B is a light pendulum rod of gum lac, turning on a centre at A, and its upper knob B playing between the electrified knobs C and D; the knob B of the pendulum is alternately attracted and repelled by the electrified knobs C and D. This motion will often continue for years without intermission.

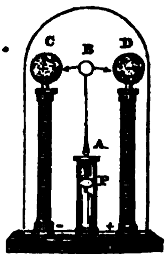


Fig. 10[illegible]

Bohnenberg's Electroscope.

One of the most useful applications of the dry pile is exhibited in the construction of an electroscope, represented in Fig. 103, which is not only the most sensitive of all others, but has the additional property of at once indicating the peculiar kind of electricity of the body applied to it.

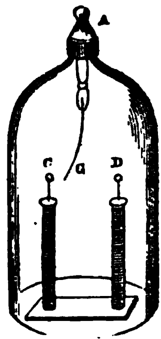


Fig. 103.

This instrument consists of two dry piles C and D, placed as in Zamboni's perpetual motion; between the knobs C and D, a single gold leaf G is suspended in the same manner as in the ordinary gold leaf electroscope. The moment the gold leaf G is electrified by the approach of any electrified body towards A, it is carried either towards one knob or the other, according to the nature of the electricity with which the body is charged; that is to say, if the electroscope be charged with positive electricity, then the gold leaf G will be attracted towards the negative knob of the pile, and so on.

MAGNETISM.

THE MAGNETIC POWER.

1. SUBSTANCES endowed with *magnetism* attract pieces of iron, and the substances possessing this property are called *magnets*. Magnetic substances possess various other remarkable properties, which shall hereafter be described. There are two kinds of magnets — natural magnets and artificial magnets.

Natural Magnets, or loadstones, are iron ores, found at almost every place on the earth. The ancient Greeks were acquainted with the attractive property of the natural magnet, or loadstone; they gave the name of magnet to this mineral, probably because it was found most abundant in the vicinity of Magnesia, a city of Lydia, in Asia Minor.

Artificial Magnets are generally made of steel bars; and the way in which the magnetic property is imparted to them will shortly be described. Artificial magnets are named according to their shape; thus, we have the *bar magnet*, represented in Fig. 1, and the *horseshoe magnet*, represented in

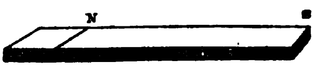


Fig. 1

Fig. 2.

Fig. 2. When several bar magnets or horseshoe magnets are combined, the whole is called a *magnetic battery*, or a *compound magnet*.

The magnetic power of a magnetized bar chiefly resides in its extremities, which are called the magnetic poles; one being called the north pole of the magnet, and the other the

south pole. In order to distinguish these poles from each other, a mark is usually drawn across the extremity corresponding to the north pole of the magnet.

One of the most remarkable properties of the magnet is, that it communicates its properties to a steel bar or needle that is rubbed for a few times, in the same direction, across one of its poles.

MAGNETIC ATTRACTION.

2. *Exp.* 1. Sprinkle some iron filings on a magnetic steel bar; the iron filings will be attracted to the extremities or poles of the magnet, whilst the other portions will be left nearly bare, as shown in Fig. 3.

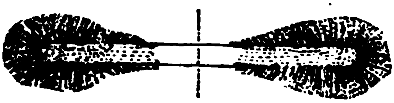


Fig. 3.

When the steel bar exceeds eight or ten inches in length, we *sometimes* find two other poles besides those that are at the ends, as shown in Fig. 4.

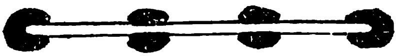


Fig. 4.

Exp. 2. Attract a series of pieces of iron wire *a b c* to the extremity N of the magnetic bar N S, as shown in Fig. 5. Here the wires, while they are in connection with the magnet N S, become a series of little magnets, whose lower extremities are all north poles; that is, of the same name as the pole of the magnet to which they are attached.

Exp. 3. *To magnetize a penknife.*—Rub the knife, for several times, *in the same direction*, that is, from haft to point, across one of the extremities, or poles, of a magnet; apply the point of the knife to some iron filings, or small pieces of iron: they will be attracted to the point of the knife.

Fig. 5.

The attraction between a magnet and iron is reciprocal.—Whilst the magnet attracts iron, the iron also attracts the magnet.

Exp. 1. Suspend a piece of iron wire by a thread, so that the wire may hang horizontally. Bring the one extremity of a magnet near to one end of the wire; the wire will be attracted by the magnet.

Exp. 2. Suspend a magnetized needle in the same manner; bring the extremity of the iron wire near to either pole of the magnet; the magnet will be attracted by the iron wire.

Magnetic Attraction transmitted through various Bodies.

Exp. 1. Interpose a thin screen of wood, or glass, or copper, or any substance excepting steel and iron, between the magnet and the iron wire of the foregoing experiments; the attraction will take place just as if there were no substance interposed.

Exp. 2. Strew some iron filings on a sheet of white paper; place the pole of a magnet beneath them; the filings will appear to move in whatever direction the magnet is moved.

Exp. 3. Interpose an iron plate between a magnet and an iron wire suspended by a thread; the magnet will have little or no effect upon the wire.

Distribution of Magnetism in a magnetized Bar.

The inequality of this distribution may be readily proved by the following experiments.

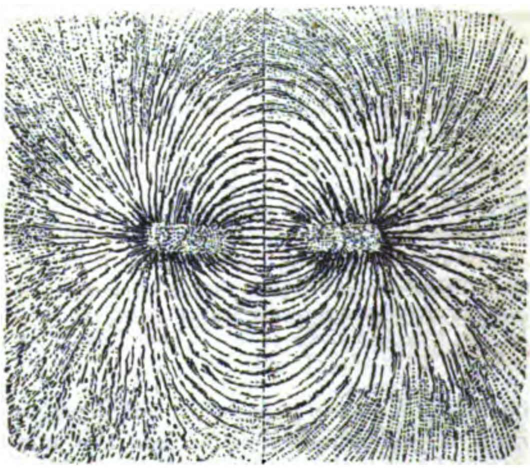


Fig. 6.

Exp. 1. Strew some iron filings on a sheet of white card paper, beneath which a bar magnet has been placed; occasionally tap the paper to facilitate the arrangement of the filings. The beautiful distribution of the filings (as exhibited in Fig. 6) around the bar, shows the manner in which the attractive force of the different points in the bar vary—the filings are most accumulated round the two poles, towards which they seem to converge from all parts, as to the principal centres of action: on the other hand, the central portion of the bar scarcely attracts any of the iron filings, thereby showing that the centre of the bar is a neutral point; that is to say, it does not possess any attractive power. The curves formed by the filings are known by the name of the magnetic curves.

This experiment furnishes us with a ready method of detecting the poles of a natural magnet.

Exp. 2. Take a magnetic bar N S, (Fig. 7,) and support it at its middle point C; apply at any number of equidistant points *a*, *b*, *c*, *c'*, *b'*, &c.,

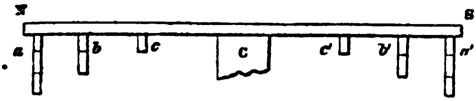


Fig. 7.

a series of pieces of soft iron wire; then it will be found that the number of pieces of wire which the magnet can support will increase as we approach the extremities or poles N and S.

The centre C of the bar has been called the *neutral point*, or *point of magnetic indifference*, and the poles are those two points where the greatest attractive force is found to reside, which in this case are at the extremities. The term *pole* is sometimes taken to mean that point in each half of the bar where the greatest attractive force will be accumulated, supposing the magnet to be acting upon a piece of iron or steel placed at a little distance from it; in this case the poles are, on an average, at the distance of about one tenth of an inch from each extremity.

MAGNETIC POLARITY.

DIRECTIVE PROPERTY OF THE MAGNETIC NEEDLE.

3. A magnetized steel needle, suspended horizontally by a thread, or on a fine point, will always point very nearly north and south. This is called the *directive* polarity of the magnet. This direction is so constant, that, when the needle is displaced, it returns exactly to it, after a few vibrations. Moreover, the same extremity of the needle always points to the north, and the same extremity to the south; so that if the needle be turned half way round, it will not rest until it has resumed its original position. The extremity which points towards the north is called the north pole of the magnet, and that which points towards the south, the south pole of the magnet. This remarkable property has been of great use to navigators.

Magnetic needles are usually constructed after the form shown in Fig. 8; where the needle turns upon a vertical point, which enters the conical cap screwed into the centre of the needle.

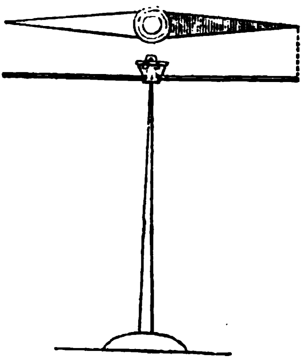


Fig. 8.

The direction in which the needle points has been called the line of the *magnetic meridian*. This line does not exactly coincide with the direction of the geographical meridian, as we shall hereafter more fully explain. At London, the needle at present points about 24° west of the true north. This is called the magnetic *variation*, or magnetic *declination*. This declination is not the same for all places on the earth, and it is continually changing for all places on the earth.

Exp. 1. Magnetize a small sewing needle; place the needle on some water, so as to make it float: after a little time the needle will settle itself, and will point in the direction of north and south. If the needle be shifted from this position, it will return to the same position again when left to itself. This experiment may also be readily performed in the following manner: —

Exp. 2. Take a strip of card paper A B; suspend it upon the point S of a pin passed through a cork; place the magnetized needle N S upon one side of the strip of card paper; restore the balance by placing some small weight W upon the opposite side of the card; then the card will turn round until it points north and south, as before described.

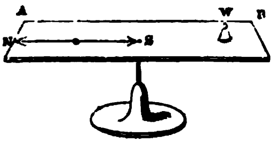


Fig. 9.

With any of these needles the following experiments may be performed, (excepting the cases specified.)

4. Iron or steel attracts both poles of the needle.

Exp. 3. Hold a bit of iron near either of the poles of the needle; the needle will follow the iron; by moving the iron round, the needle will revolve on its centre in the same direction.

Exp. 4. By holding a bit of iron near to the sewing needle of Exp. 1, it may be made to float about in any direction.

Exp. 5. *The magnetic swan.* — This philosophical toy consists of a piece of thin sheet iron, made into the shape of a swan, so as to float upon water.

When the point of a magnet is presented to the swan, it appears to swim towards the point.

5. The like poles of magnets repel one another, and the unlike poles attract. This law of magnetism is exactly analogous to the law of attraction and repulsion of the two kinds of electricity.

In order to distinguish these opposite influences, the magnetic principle of the north pole is called *positive magnetism*, or +, and that of the south pole, *negative magnetism*, or —.

Exp. 6. Bring the north pole of a magnet near to the south pole of the needle, and it will be attracted. Bring the north pole of a magnet near to the north pole of the needle, and it will be repelled; and so on. This always enables us very readily to ascertain the particular poles

of a magnet, or to determine whether or not a metal bar possesses magnetism; for the extremity of the bar which attracts the north pole of a needle will be the south pole of the bar, and the other extremity will be the north pole.

Exp. 7. Hang a small key to the north pole of a magnet; present the south pole of another magnet to the upper extremity of the key: the key will instantly fall. Here the two different kinds of magnetism neutralize each other's effects.

Exp. 8. Immerse the like poles of two magnets into some iron filings; bring the two poles together, and the filings will fall. But if the poles are unlike, the filings will move towards each other.

Exp. 9. Balance a bar magnet upon a common pair of scales; bring the pole of another magnet immediately beneath one of the poles of the magnet placed on the scale; then, when the poles, thus brought near to each other, are of the same kind, the scale will ascend from the repulsion of the magnets; and, on the contrary, the scale will descend when the poles are of different kinds.

6. If a magnet be broken, each part becomes a perfect magnet.

Exp. 10. Break a magnetized knitting needle; test the polarity of each end of the pieces; the poles of the two magnets will lie in the same direction as the poles of the original magnet.

THEORY OF MAGNETISM.

7. The theory of magnetism is exactly analogous to the theory of electricity. The magnetic fluid, in its quiescent state, is supposed to consist of two distinct fluids — the one being the *north* or *positive magnetism*, the other the *south* or *negative magnetism*. When these two fluids are combined, they form the magnetic fluid as it exists in non-magnetized substances, or substances in a neutral state. The particles of the same kind of magnetism repel each other; but the particles of opposite kinds of magnetism attract each other. When the two fluids exist in a body so as to neutralize each other, then the body exhibits no magnetism; but if this state of equilibrium be disturbed by any cause, then the magnetic state is induced.

Fig. 10 gives a visible representation of this supposed distribution of the particles of the two magnetic fluids in the body of a magnetic bar.

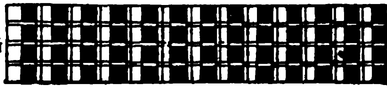
N  S

Fig. 10.

Here we suppose the light squares to represent the particles of the positive fluid, and the dark squares the particles of the negative fluid. As the particles of the two fluids are separated from one another, they must arrange themselves according to the law of attraction and repulsion assumed in the theory; that is to say, a positive and a negative particle must always be contiguous to each other. From this it follows that the extremity N will be a north pole, and S a south pole.

This theory readily enables us to explain all the phenomena of magnetism. Let us take a few examples: —

When the extremity of a bar of soft iron is placed in contact with the north pole of a magnet, the opposite extremity of the bar also exhibits north or positive magnetism; this takes place in consequence of the repulsion of the positive fluid from, and the attraction of the negative fluid to, the north pole of the magnet.

When a magnetic needle is broken, it is obvious that the arrangement of the particles of the two fluids must remain unchanged; that is to say, the poles in the two magnets must lie in the same direction as the poles of the original magnet.

When the north pole of a magnet attracts a piece of iron wire, the extremity of the wire next to the north or positive pole of the magnet becomes a south or negative pole, owing to the repellent action exerted on the positive fluid, and the attractive action on the negative fluid of the wire, by the positive fluid of the magnetic bar; hence the magnet attracts the wire according to the law that bodies magnetized with different fluids attract each other. This also explains the great law of magnetic induction, which we shall shortly consider.

The like poles of two magnets repel each other by virtue of the mutual repulsion subsisting between the particles of the same kind of magnetic fluid; and the unlike poles of two magnets attract each other, in consequence of the mutual attraction subsisting between the particles of the two different kinds of the magnetic fluid.

The north pole of the needle is directed towards the north pole of the earth, because the earth itself is a great magnet, having its negative magnetic pole lying towards its north geographical pole, and its positive magnetic pole lying towards its south geographical pole.

The dip of the magnetic needle may be readily explained by considering the dipping direction of the needle to be the direction of the resultant of the magnetic forces residing in the earth, which act upon the needle. But this subject will be hereafter more fully explained.

8. The attractive force of magnets decreases with the distance.

Exp. 11. Place the south pole of a magnet at a distance from the north pole of the needle, and a little to the right or left of it: then the needle will be deflected a little from its north and south direction; now bring the magnet a little nearer to the needle, and its deflection will be increased, and so on — thereby showing that the attractive force of the magnet increases as we decrease the distance.

It will also be observed that the needle vibrates more and more rapidly as the magnetic bar is brought more closely to it. Now, the rapidity of these vibrations obviously depends upon the amount of the magnetic force.

The law of the attractive force of a magnet, with respect to distance, is the same as the law of gravitation; that is to say, *the attractive force of a magnet varies inversely as the squares of the distance.*

MAGNETIC INDUCTION AND CONDUCTION.

9. When a wire of soft iron is placed in contact with the pole of a magnet, it becomes, as it were, a part of the magnet itself; for *every portion* of the wire has the same polarity as the extremity of the magnet with which it is in contact. This may be called magnetic conduction. But if the contact be ever so slightly broken, the wire becomes a complete magnet having two poles; and this takes place in consequence of the operation of another principle,—that of induction,—which now claims our attention. When the soft iron wire has been entirely removed from the magnet, after a short time it no longer possesses any magnetic properties; it, in fact, was only decidedly magnetic while it was in contact with or very near to the magnetized bar. Soft iron receives the magnetic influence most easily; but it also parts with it most easily, when taken away from the magnet. Steel and cast iron are not so easily magnetized; but when the magnetic property is once imparted to them, they retain it for years, unless they are subject to some counteracting influence.

Magnetic induction is that influence which a magnet exerts upon substances at a distance from it.

Let N S be a magnetic bar, N being its north pole, and S its south pole; *n s* a soft iron bar, having its extremity *s* placed near to the extremity N of the magnet; then the soft iron bar *n s* will be a perfect magnet so long as the pole of the magnet N S is near to its extremity *s*;

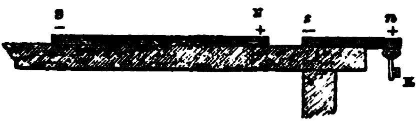


Fig. 11.

the extremity *n*, in fact, will be its north pole, and *s* its south pole. To render the magnetic induction apparent, a small key may be suspended from the extremity *n*. The nearer the bar N S is brought to the bar *s n*, the more powerful will be the magnetism induced in it. Let the magnet

N S be taken away; then, after a short time, the little key *k* will fall off the bar *s n*, and it will soon lose all traces of magnetism.

Here the positive fluid at N repels the positive fluid from the extremity *s*, and at the same time attracts the negative fluid; hence the equilibrium of the two fluids in the soft iron *n s* is disturbed, the extremity *s* being in a negative magnetic state, and the extremity *n* in a positive magnetic state; or, in other words, *s* becomes a south magnetic pole, and *n* a north magnetic pole.

Bring the south pole of a bar near to *n*: then the magnetic induction will be doubled; the lower extremity of the little key *k* will rise towards this south pole; and a much heavier key may be supported by the extremity *n*. Now bring the north pole of a bar near to *n*: then the key *k* will instantly drop off; in this case, the two poles, being of the same kind, counteract each other's influence.

A series of soft iron bars may be magnetized in the same manner. Thus, let A be a strong magnetic bar; B, C, and D a series of soft iron

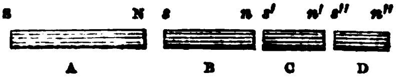


Fig. 12.

bars placed near each other, as shown in Fig. 12: then all these soft iron bars, from the action of induction, will become perfect magnets, having their poles as indicated by the letters of the figure.

The law of magnetic induction is exactly analogous to the law of electrical induction.

The following simple experiments will render the law of magnetic induction and conduction more apparent.

MAGNETISM BY CONTACT.

10. *Exp.* 1. Place a long piece of soft iron wire in contact with the north pole of a powerful magnet; test the magnetism of the wire by means of a magnetic needle; the south pole of the needle will be every where attracted by the wire, thereby showing that the wire possesses north polar magnetism.

Exp. 2. Cut some short pieces of iron wire; present the end of one of them to the pole of a strong magnet: it will be immediately attracted; the free end of this wire will now attract a second wire, and this in its turn will attract a third wire, and so on. All these wires become

little temporary magnets, owing to their connection with the pole of the magnetic bar. In like manner the phenomena of the iron filings adhering to the pole of a magnet may be explained: each filing, thus suspended, is converted into a little magnet.

MAGNETISM BY INDUCTION.

11. *Exp.* 1. Place the extremity of a long iron wire opposite to the north pole of a magnetic needle; bring the north pole of a magnetic bar near to the opposite extremity of this wire: the needle will be instantly repelled.

Exp. 2. Suspend two pieces of soft iron by a thread, as shown in Fig. 13; bring the north pole of a magnet close to the lower extremities of the wires: the wires will repel each other, after the manner shown in the figure.

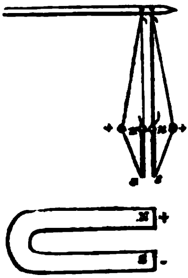


Fig. 13.

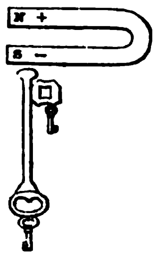


Fig. 14.

Exp. 3. Hold a large key near the pole of a powerful magnet: then, as the key becomes a magnet by induction, it will carry two small keys, one at its lower extremity, and the other at its upper extremity, as shown in Fig. 14.

THE DIP OF THE MAGNETIC NEEDLE.

12. Besides the directive property, the magnetic needle, when freely suspended, has another remarkable property, called its *dip*, whereby its north pole dips towards the north pole of the earth in our hemisphere, and its south pole towards the south pole of the earth in the southern hemisphere.

At present, the magnetic dip at London is about 67°.

This property may be readily verified in the following manner: —

Experiment. Thrust a knitting needle *n s* through a cork *c*, as shown in Fig. 15; at right angles to this needle thrust a fine sewing needle through the cork, which will form the axis of the needle *n s*; attach an untwisted thread *a d b* to the axis, and suspend the whole by the extremity of the thread, taking care to thrust *n s* either one way or the other, until it is suspended in a perfectly horizontal position. Now magnetize the needle *n s*, which may readily be done by simply keeping it for a short time across the two poles of a horseshoe magnet. Again suspend the needle, and it will be found that its north pole will dip towards the north. Care must be taken, in magnetizing the needle, not to disturb the axis.

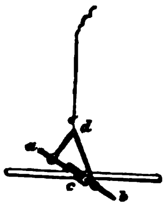


Fig. 15.

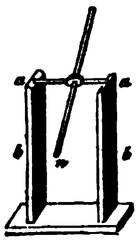


Fig. 16.

This experiment may be performed with more precision by placing the axis *a a* between two upright supports *a b*, *a b*, as shown in Fig. 16. The best supports for the axis are the edges of two wine glasses.

The angle which the *dipping needle* makes with the horizon at any place is called *the angle of the needle's dip* at that particular place. This angle is not the same for all places. At places in the northern hemisphere, the north pole of the needle is depressed; and at places in the southern hemisphere, the south pole of the needle is depressed. At places near to the equator, the needle has no dip — that is to say, it hangs horizontally.

Instruments constructed for the purpose of exactly observing the dip have a vertical graduated circle connected with them, and also a screw adjustment for placing the axis exactly horizontal, as shown in Fig. 17.

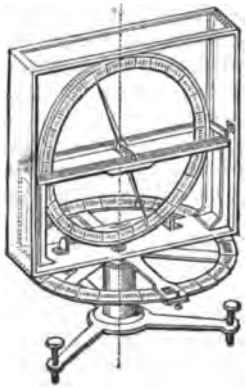


Fig. 17.

Fig. 18.

Fig. 18 represents a simple form of magnetic apparatus for showing the direction of the needle, as well as its dip. By this contrivance, the needle *n s* has a twofold free motion, viz., a free motion with respect to its directive property, and a free motion, on its horizontal axis *f f*, with respect to the angle of its dip. *a b c d* is a light frame suspended by an untwisted thread; the horizontal axis *f f* of the needle turns freely in the sides *a b* and *d c* of the frame. A needle, thus suspended, will settle itself in the plane of the magnetic meridian, and will also assume the true angle of the dip.

The subject of magnetic variations, &c., will be more fully explained in connection with that of terrestrial magnetism.

TO MAGNETIZE STEEL BARS, &c.

I. TO MAGNETIZE A NEEDLE WITHOUT USING AN ARTIFICIAL MAGNET.

13. Fix the needle, against the edge of a table, in the magnetic meridian — that is, nearly north and south; hold a long poker above the needle, and another one below it, as shown in Fig. 19; then move the pokers in contrary directions until they come to the positions shown in Fig. 20; repeat this operation for several times, always observing, at every successive operation, to move the pokers in the same manner, and the needle will be magnetized. Here the pokers, being held in the direction of the magnetic dip, really become magnets. (See the subject of Terrestrial Magnetism.)

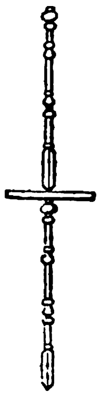


Fig. 19.

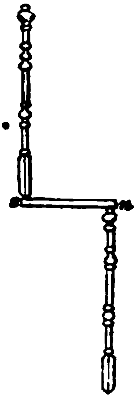


Fig. 20.

II. TO MAGNETIZE STEEL BARS, &c., BY MAGNETS.

14. There have been various processes devised for magnetizing steel bars. The following are amongst the most simple and efficient: —

Most easy Methods of magnetizing a small Needle.

Exp. 1. Bring the pointed extremity of a sewing needle in contact with the south pole of a magnet; let the needle remain in contact for a few minutes; on separating them, you will find that the pointed extremity has become a north pole, and the other a south pole.

Here it will be observed that the end of the needle in contact with the pole of the magnet acquires an opposite or dissimilar magnetism to that of the pole. The equilibrium of the two magnetic fluids in the needle is disturbed by the pole of the magnet at the point of the needle, the dissimilar magnetic fluid is attracted by the pole, and the similar fluid is repelled.

Exp. 2. Rub one end of the needle, in the same direction, across the north pole of the magnetic bar, and then rub the other extremity of the needle across the south pole of the bar: then the former extremity of

the needle will be a north magnetic pole, and the other extremity a south magnetic pole.

Exp. 3. Place the needle across the two poles of a horseshoe magnet; let it remain there for some time; on removing it, you will find that the extremity in contact with the north pole of the magnet has become a south pole, and the other a north pole.

Exp. 4. Place the middle of a needle on the north pole of a magnet; on separating them, you will find that the middle of the needle is a south pole, and that its extremities are north poles. This will form a pretty good astatic needle.

Exp. 5. With the pole of a good magnet, draw any figure upon the surface of a clear steel plate; sprinkle iron filings upon it: the filings will remain suspended at all those points which the pole of the magnet has touched.

Exp. 6. Place one pole of a magnet in the middle of the steel bar; draw the magnet along to the end of the bar; return the magnet, through the air, to the middle of the bar, and repeat the stroke in the same direction; repeat this operation for several times. Next place the other pole of the magnet in the middle of the steel bar, and proceed as before, observing that, in this case, the magnet must be drawn to the opposite extremity of the steel bar.

This process has been called the method of *single touch*.

The Method of Double Touch.

15. This process consists in touching the steel bar which we wish to magnetize with both poles of the magnet at the same time. This method is always employed when large steel bars are to be magnetized.

Fasten two bar magnets together, so that their dissimilar poles may be about one eighth of an inch asunder; this will be most readily effected by inserting a piece of card paper between them, and tying them with a piece of cord. Place this double magnet vertically upon the middle of the steel bar; draw the magnet to the end of the bar; return the magnet, through the air, to the other end of the bar; draw the magnet, as before, to the opposite end; repeat this process for several times, taking care to keep the pole of the compound magnet always in the same relative position, and to stop the process when the magnet has arrived at the middle of the bar. The operation should be performed on both sides of the bar.

A horseshoe magnet, having its poles near together, will answer the same purposes as the double magnet just described.

This method may be employed to magnetize two or more bars at the same time.

Place two steel bars, N S, N S, of the same size, parallel to each

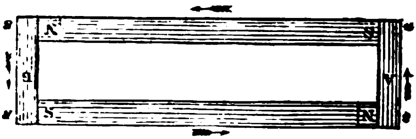


Fig. 21.

other, and connect their extremities with two pieces of soft iron, A and B. (See Fig. 21.)

Place the pole of the double magnet on the middle of one of the steel bars, and move it completely round the frame, constantly keeping the poles of the double magnet in the same direction; when you have completed about a dozen revolutions, turn the plates and proceed as before. The poles of the steel bars will have a reverse position to the poles of the double magnet.

To magnetize Horseshoe Bars.

Fig. 22 shows the method of magnetizing one horseshoe bar N. Place a piece of soft iron K, called a *keeper*, across the extremities of the horseshoe; place a horseshoe magnet M, whose legs are at the same distance apart as those of the bar N, with its poles perpendicular to the keeper K;

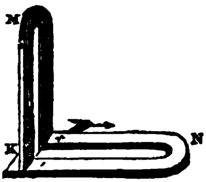


Fig. 22.

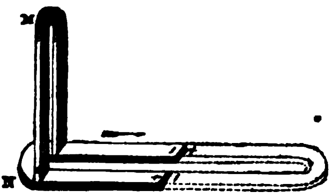


Fig. 23.

draw the magnet towards the bent part of the horseshoe; when it has arrived there, lift it off, and bring it back to its first position; repeat the operation for about a dozen times; then turn the horseshoe bar, with its keeper still on, and repeat the operation as before; and so on.

The polarity of each leg of the horseshoe bar will be similar to that of the leg of the magnet first placed in contact with it.

Fig. 23 shows the method of magnetizing two horseshoe bars at the same time. The bars are placed with their extremities in contact; and

the horseshoe magnet M is moved from the curved part of one bar to the curved part of the other, constantly in the same direction.

The following is also a convenient and efficient mode of arrangement (see Fig. 24) for magnetizing bars.

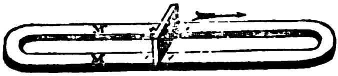


Fig. 24.

M M is the horseshoe magnet, placed with its poles against the extremities of the horseshoe bar to be magnetized; A is a soft iron keeper extending between the legs of the horseshoes; this keeper, or feeder, is drawn in the same way as the magnet represented in Fig. 23.

In the same manner, straight bars may be magnetized.

In Fig. 25, M M represents the magnet, A the feeder, B B the two bars to be magnetized, and K their keeper.

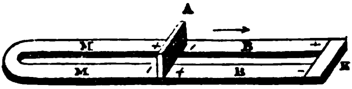


Fig. 25.

When magnetic bars are not in use, they should always be put away with their keepers upon them; this not merely preserves their magnetism, but also tends to increase it.

A compound horseshoe consists of a number of horseshoe magnets bound together by screws, and connected at their poles by means of a keeper, as shown in Fig. 26.

Fig. 27 represents a lot of bars bound together in the same manner.

Fig. 26.

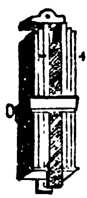


Fig. 27.

On the best Quality of Steel for making Magnets.

16. The steel best suited for artificial magnets is of a fine grain, of uniform structure throughout, and free from flaws. A principal requisite is, that it should possess a proper degree of hardness, and that it should be equally hardened, throughout the entire mass; for if too hard, it is extremely difficult

to impart to it any magnetic virtue; and if too soft, it readily loses it when given. It has been found most advantageous to make the steel in the first instance brittle, like glass, and then to heat it a second time, till it becomes of a straw or violet color.

The capacity and tenacity of artificial magnets are also affected by their form and dimensions. It has been ascertained that the breadth of a bar magnet should be about one twentieth of its length, and its thickness from one fourth to one third of its breadth. In a horseshoe magnet, the space between the two poles ought not to be greater than the thickness of the bar of which the magnet consists. Lastly, it is necessary that both bar and horseshoe magnets be well polished, and that their faces be as level as possible.

Magnetism is readily excited in soft Iron Bars.

17. A bar of soft iron, placed in the direction of the magnetic dip, becomes magnetic from the inductive influence of the earth acting like a magnet upon the bar. A few blows applied at one extremity of the bar, thereby causing its particles to vibrate, will generally aid the inductive influence of the earth.

A bar of iron heated to redness, and allowed to cool after being placed in the direction of the magnetic dip, will acquire a certain degree of magnetism. Hence pokers and iron rails, which have been kept for a long time standing in a somewhat vertical position, are generally found to possess a low degree of magnetism.

A piece of iron wire may be rendered magnetic by twisting it until it breaks; and, in like manner, files and gimlets, after having been some time in use, become so much magnetized as to attract iron filings.

Voltaic electricity is the most powerful means of rendering bodies magnetic.

Experiment. Allow a magnetic needle N S to assume its north and south direction; take a non-magnetized poker, and hold it in a horizontal position and at right angles to the direction of the needle, so as to bring one of its extremities, say its lower extremity, near to the north pole of the needle; the needle will, of course, be attracted, if the poker is not magnetic; now hold the poker in the direction of the magnetic dip, as shown in Fig. 28, and the north pole N will be repelled — thereby showing that the lower extremity *n* of the poker is a north magnetic pole. The effect will be increased by striking the head *s* of the poker with a hammer.

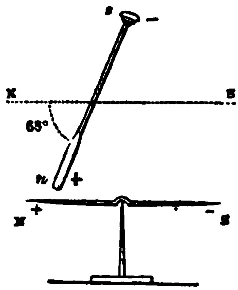


Fig. 28.

TERRESTRIAL MAGNETISM.

18. In order to account for the directive and dipping properties of the needle, it has been stated that we must regard the earth as a great magnet, having a negative magnetic pole lying towards the north geographical pole, and a positive magnetic pole lying somewhere towards the south geographical pole. The following experiment is highly calculated to illustrate this theory.

Experiment. Place a magnetic needle (see Figs. 29 and 30) *n s* over the middle part A of a magnetic bar N S; in this position the needle is

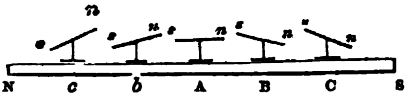


Fig. 29.

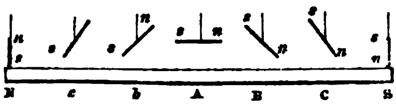


Fig. 30.

exactly horizontal, and the south pole of the needle is directed to the north pole of the magnet, and the north pole of the needle to the south pole of the magnet. Thus we can assign a cause for the directive property of the needle. Now slowly move the needle along the bar from A to S; at the position B the north pole of the needle dips towards the south pole of the magnet; at the position C, the north pole of the needle dips still more towards the south pole of the magnet; and at S the needle hangs vertically, with its north pole pointing to the south pole of the magnet. Now, in like manner, move the needle from A to N; at the position *b* the south pole of the needle dips towards the north pole of the magnet; and so on as before. (In Fig. 30 the needle is supposed to be suspended by a thread.) Thus we can account for the magnetic dip.

The phenomena of the direction and dip of magnetic needles at different parts on the earth's surface are found to coincide with the effects which a bar magnet produces on the needle, as above described; hence we are led to conclude that the earth is a great bipolar magnet, whose poles lie towards the geographical poles of the earth. As like poles attract, and unlike poles repel each other, it follows that *the magnetic pole of the earth lying towards the north is a negative magnetic pole*, and that *the one lying towards the south is a positive magnetic pole.* The former magnetic pole is situated in North America, in the vicinity of Hudson's Bay, in 70° 5′ N. lat., and 114° 55′ W. long.; and the other in 72° 35′ S. lat., and 152° 30′ E. long. At these places the dipping needle assumes a vertical position, as shown at P and K, Fig. 31. Sir James Ross found the pole P in the northern hemisphere during his arctic expedition of 1829. The actual existence of the magnetic poles in these places is further confirmed by the fact that the magnetic needle, at different parts on the earth's surface, is always directed towards these points as magnetic poles.

At the *magnetic equator* M T the needle assumes a horizontal position. As we approach the magnetic pole P, the north pole of the needle dips more and more; and, on the contrary, as we approach the magnetic pole K, the south pole of the needle dips more and more. On the *magnetic meridian* K G P, K V P, &c., the needle has always the same general

direction, although it varies in its dip. Let N S represent the axis of the earth, E Q its geographical equator, S V N a geographical meridian,

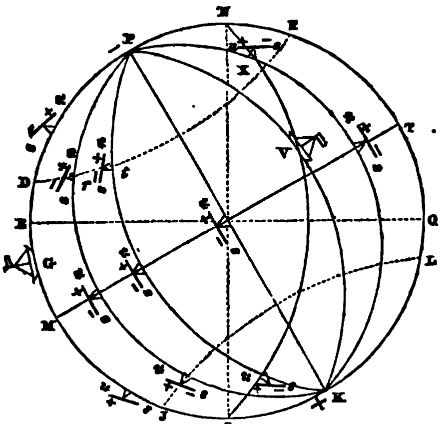


Fig. 31.

K V P, K X P, magnetic meridians; then the angles P V N and P X N will be the declinations, or angles of variation, of the magnetic needle at the points V and X, respectively. The commander of a ship at V, knowing from his charts the deviation of the needle at the particular spot, will be able to ascertain the true north and south. The *magnetic parallels* D F, J L, &c., are *lines of equal magnetic dip*, as shown at *r* and *t*, on the magnetic parallel D F, where the needles *s n*, *s n*, dip towards the pole P, at the same angle.

It must be borne in mind that these different magnetic lines upon the earth are not exactly formed by true sections of the sphere, like the geographical circles. Indeed, some of these magnetic lines have the shape of looped curves, or curves of double curvature, differing more or less from the circular lines shown in Fig. 31.

The lines of equal dip have been called *isoclinic lines;* these lines, as we have shown, surround the globe, running nearly parallel with the magnetic equator. It is a remarkable fact, that there is a coincidence subsisting between these lines and the isothermal lines, or lines of equal heat, upon the globe: this coincidence indicates that the earth's magnetism is intimately connected with terrestrial heat.

The inductive influence of the earth upon bars of soft iron (see *experiments*, p. 13 and 26,) bears a striking analogy to the induction of magnetism by ordinary magnetic bars. The magnetic effects of the earth are undoubtedly attributable to the inductive influence of terrestrial magnetism.

VARIATIONS OF THE NEEDLE.

19. The earth's magnetic powers are subject to both regular and irregular variations. These variations are indicated by the changes which occur at the same place, in the declination and dip of the needle, and in its magnetic intensity.

The regular variations follow a certain law, which enables us to calculate beforehand the changes that in future will take place. These regular variations are either secular or periodic. The secular changes become only evident after the lapse of years, and the periodic are those which, as it were, oscillate within short periods of time.

Of all the secular variations, the declination is that which has been most observed, and which has been most exactly determined. The dip and intensity have but recently claimed the attention of philosophers.

About the year 1600, the needle at London pointed $4\frac{1}{2}°$ to the east of the north; 1660 it pointed due north; from which time it gradually deviated to the west of the north until the year 1818, when it deviated 24·3° to the west of north, which was its maximum deviation; but for the last 30 years its declination has certainly been decreasing, and in all probability it will continue to do so until it again becomes due north; then the declination will increase towards the east until the needle has again attained its maximum eastern declination, when it will again return.

All that is known with certainty relative to the dip of the needle is, that at present it is decreasing in Europe. The maximum dip of the needle at London took place about a century ago, when it was about 74°; since that time it has been going on decreasing, with great regularity, at the rate of 3′ annually. At London, the dip of the needle at the present time is about 68°.

The variation of the magnetic intensity has but recently claimed the attention of experimentalists; however, it seems highly probable that this intensity is at present decreasing in Europe.

The compass needle, also, undergoes diurnal and annual variations. These variations appear to be intimately connected with the heat of the sun. From sunrise to a little after noon, the north pole of the needle moves towards the west, and after that time it retrogrades towards the east until a little after sunset in the evening, when it remains nearly stationary until sunrise. The extent of these variations depends, not only on the time of the year, but also upon the situation of the place. In London, during the heat of summer, the variation is about 19′, whereas, in winter, it is only about 7′. In Paris, the summer variation is about 15′, and in winter about 9′. These variations disappear under the magnetic equator; and on the south of it they are found to exist in an inverted order.

The dip of the needle is also subject to daily variations, which also appear to depend upon the action of the sun's heat upon the earth; but they do not exactly accord with the daily variations of declination.

The variations of magnetic intensity also appear to depend upon the sun's heat.

The irregular magnetic variations are connected with certain electrical and meteoric phenomena, such as the aurora borealis, lightning, and even volcanic eruptions. A flash of lightning has been known to reverse the poles of a needle, and even to destroy its magnetism entirely.

THE DECLINATION COMPASS AND MARINER'S COMPASS.

20. This apparatus is used for observing and measuring the declination of the needle, or, conversely, for determining the north and south direction, or the meridian line, when the magnetic declination is known. It consists of a magnetic needle N S (see Fig. 32) delicately suspended by means of an agate or steel cap O resting on a pivot. E F is a graduated circle, on which is read the division corresponding to the position of the needle. The needle, with its graduated circle, is placed in a circular box covered with glass. The instrument is usually furnished with a telescope A B, turning on a horizontal axis C D, which carries an air level and a vertical quadrant A, divided to measure the angles described by the telescope. The box is capable of turning round on a vertical axis, by which it is fixed on its stand, in order to bring the telescope in the direction of the meridian; then the angle formed by the direction of the telescope, with the direction of the needle, gives the angle of declination; or, when the declination is known, the box is turned until the angle made by the axis of the telescope and the direction of the needle are equal to it; then this gives the position of the meridian.

The *marine compass* differs from the ordinary compass simply in having a double suspension, which admits of its maintaining itself in a hor-

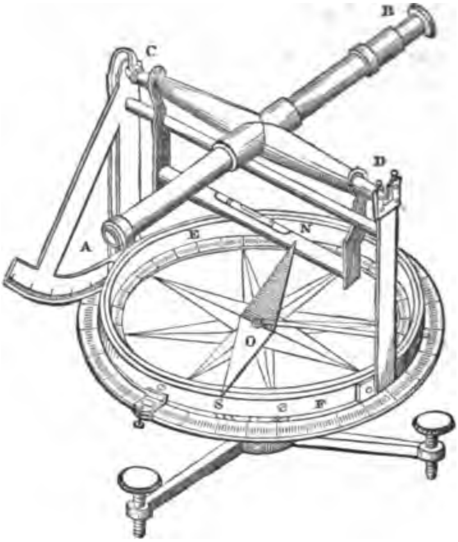


Fig. 32.

izontal position, notwithstanding the rolling of the ship. Fig. 33 represents a form of this double suspension; where C is the agate or steel

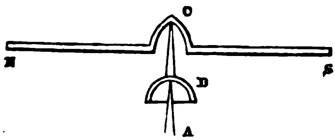


Fig. 33.

cap fixed to the needle N S; D another cap, with a pivot fixed to its upper part, on which cap C turns; A the pivot on which the cap D turns.

THE ASTATIC NEEDLE.

21. For the purpose of conducting many interesting experiments, it is requisite to have magnetic needles on which the earth does not exert any

directing influence: needles of this sort are called *Astatic needles*. This object is readily attained by fixing two equal needles to a common point of suspension, with their contrary poles together. By this means, the one needle exactly counteracts the directive tendency of the other, so that the compound or astatic needle will be free to obey the slightest attractive force, without being influenced by the magnetic power of the earth.

Fig. 33*a* represents a simple and highly serviceable astatic needle; *s n* and *n s* are two magnetic needles, of the same size and magnetic intensity, connected at their centres by a wire *a b*; the astatic needle thus formed is suspended by a fine thread of untwisted silk *a c*. The application of this astatic needle will be noticed in connection with the subject of electro-dynamics.

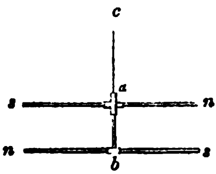


Fig. 33*a*.

The Inclination Compass.

This apparatus is used for observing and measuring the dip of the needle at different places on the earth's surface, or at different periods of time at any place. (See Fig. 17, p. 289.)

AMPÈRE'S THEORY OF MAGNETISM AND ELECTRO-DYNAMICS.

22. Ampère considered that a magnet is formed by a magnetic current, which he believed to be the same as an electric current, circulating round it constantly in the same direction, as shown in Fig. 34. Supposing the magnet to have its north and south direction, then the current enters at the south poles, and circulates round the magnet spirally, (like a corkscrew,) along its length from south to north, as shown in the figure; that is, the current is directed from east to west in the lower face of the magnet, and therefore from west to east in its upper face; or, in other words, the current is ascending in the face situated on the west, and descending in the face on the east. Steel bars become magnets when this regular current is permanently excited in them. Ampère established this theory by showing that a helix of copper wire,

Fig. 34.

through which an electric current is transmitted, possesses all the properties of a magnetic needle. As a necessary consequence of this theory, it follows that parallel currents moving in the same direction mutually attract, and that they mutually repel when they are moving in a contrary direction. Now, wires conducting electrical currents have really this property. This explains why like poles repel and unlike poles attract. But this theory will be more fully explained in connection with the subject of electro-dynamics.

VOLTAIC ELECTRICITY.

1. Galvanism, or Voltaic Electricity, is produced by a certain chemical action upon two different metals when brought into contact. Galvani, of Bologna, observed that when he touched a nerve and muscle in the leg of a dead frog with two different metals, on bringing these metals into contact, the leg underwent a convulsive motion, as shown in Fig. 35, where Z and C are the two metals brought into contact at A, the extremity B being in contact with the nerve, and D with the muscle. Galvani considered this effect as due to something in the animal structure, and hence he called it *animal electricity*, but, out of respect to the discoverer, the name of *galvanic electricity* was given to it. But Volta soon after showed that the effect was entirely due to the production of electricity by the action of the two metals upon each other, and that the nerves and muscles of the animal merely exhibited the free electricity in the same way as any other delicate electroscope might do. This leading conception conducted him to a series of splendid discoveries, and in particular, in the first year of the present century, led him to the construction of the *voltaic pile*, which stands in the same relation to voltaic electricity that the common electrical machine does to frictional electricity.

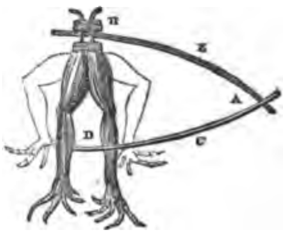


Fig. 35.

VOLTAIC PILE.

2. A number of circular plates of copper and zinc, and of cloth or card, about 3 inches diameter, were provided, and arranged in the form

of a pile, (Fig. 36.) The base of the pile is a copper disk, upon which a zinc disk is placed; (these two disks form what is called a pair;) over this pair a second similar pair is placed, observing always that the copper is below the zinc; the second pair is separated from the first by the circular cloth or card, moistened with a weak saline or acid solution. Upon the second pair is placed a third, separated also by a moistened circular piece of cloth or card, similar to that which preceded. In this manner a considerable number of pairs are placed in the same order, one over the other, and retained in their upright position by means of rods of glass. When the base plate of the pile rests upon an insulating plate of glass, this lower plate is found to be charged with negative electricity, whilst its upper plate is charged with positive electricity. These extremities are called the poles of the pile or battery, the lower extremity being the negative pole, and the upper extremity the positive pole. If the metals had been placed in a reverse order, then the poles would also obviously be reversed. Two wires, one leading from the extreme copper plate, and the other from the extreme zinc plate, conduct the electricity of the respective poles to any substance upon which the electric fluid is required to act. When the extremities of these wires are brought together, an electric spark passes between them, arising from the neutralization of the two different kinds of electricity. When these wires are held one in each hand, (the number of pairs in the pile being sufficiently great,) a rapid succession of shocks are felt. When the extremities of the two wires are connected by a very fine platinum or silver wire about half an inch in length, the neutralization of the two electricities causes this fine wire to rise in temperature, and to become red hot. The length of the fine wire which may thus be rendered incandescent is in proportion to the power of the pile.

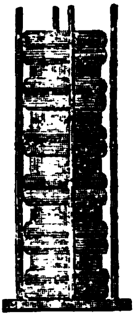


Fig. 36.

When the two wires proceeding from the two poles of the pile are immersed near each other in acidulated water, the water is decomposed into its two constituent gases, hydrogen and oxygen, the oxygen being liberated from the wire proceeding from the positive pole, and the hydrogen from the wire proceeding from the negative pole; the volumes of the gases are constantly in the same proportions that constitute water; that is to say, one volume of oxy-

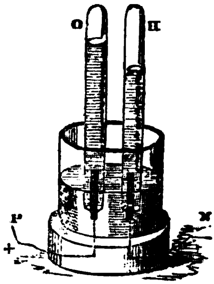


Fig. 37.

gen to two volumes of hydrogen, as shown in Fig. 37. In this experiment, the submerged parts of the two wires must be platinum.

These phenomena are merely simple examples of the various and important effects produced by the action of the voltaic pile or battery, which we shall hereafter more fully consider.

When the number of pairs in the pile is so great that its height would be inconvenient when placed in a single column, the plates may be arranged in two or more columns, as shown in Fig. 38, where the continuity of the pile is sustained by the bars B and B′. In this case, the negative pole of the pile is at N, and the positive pole at P, and the effect of the whole is the same as if the second were placed over the first, and the third over the second.

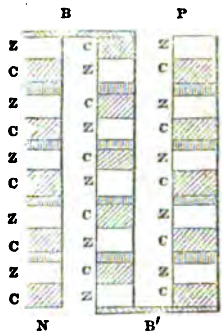


Fig. 38.

Volta proposed a second arrangement of the pile or battery, called the *Couronne de Tasses*. This form of the apparatus is represented in Fig. 39; it consists of a series of cups or glasses, containing a saline or acidulated solution. Each pair of copper and zinc plates is immersed in the separate cups; the zinc plate in one

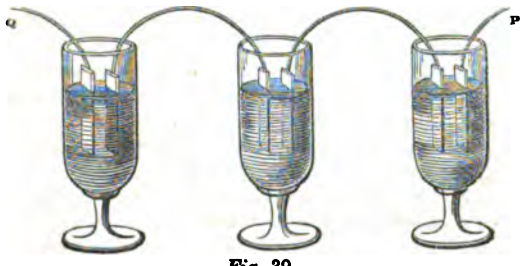


Fig. 39.

cup being connected by a wire with the copper plate in the succeeding cup, and so on; the wire Q, proceeding from the first zinc plate, forms the negative pole of the battery, and the wire P, proceeding from the last copper plate, forms the positive pole of the battery; the same, in matter of fact, as in the ordinary pile just described.

Very great improvements have been made in the construction of these batteries; but before we proceed to describe them, we shall give a few simple and instructive experiments, calculated to elucidate the general principles and effects of voltaic electricity.

PRELIMINARY VIEWS AND SIMPLE EXPERIMENTS ON VOLTAIC ELECTRICITY.

3. *Exp.* 1. Place a piece of sheet zinc *under* your tongue; lay a half crown *upon* the tongue; no peculiar sensation is felt so long as the two metals do not touch each other: now bring the edges of the two metals in contact with each other; a disagreeable taste, something like copperas, is instantly excited.

Here the saliva on the tongue between the two metals is the exciting cause of the development of the electric fluid; and when the edges of the metals are brought into contact, the voltaic circle is formed, and the peculiar sensation of taste is the effect; but when the voltaic circle is broken this sensation instantly ceases. The peculiar taste of porter, when drunk out of a pewter pot, is also due to the same cause.

Exp. 2. Instead of the half crown, in the last experiment, use a piece of charcoal or a piece of cast iron.

Exp. 3. The first experiment gave you a *taste* of voltaic electricity; now the following experiment will give you a *sight* of it.

Place a silver spoon between the gums and one cheek, and a strip of zinc, in a similar position, on the other cheek; complete the voltaic circuit by bringing the extremities of the metals together on the outside of the mouth; a slight flash of electric light will instantly be seen. Repeat the experiment: the flash will always be seen at the instant the two metals are brought into contact; and a smaller flash will be seen at the instant the contact is broken. The first experiment may be also performed by the silver tea spoon and the zinc strip.

Exp. 4. Lay a five shilling piece on a larger plate of zinc; on the coin place a live leech or a live snail; so long as the creature does not come into contact with the zinc, he appears perfectly at his ease; but the moment he moves so as to touch the zinc, thereby completing the connection between the two metals, he receives a shock and instantly recoils.

Exp. 5. Place a silver spoon S in a glass containing a solution of sulphate of copper; into the same glass insert a strip of zinc Z. No change takes place in either of the metals, so long as they are apart: bring the upper ends of the metals in contact with each other; the silver spoon will become coated with copper, which will adhere so firmly that mere friction will not take it off.

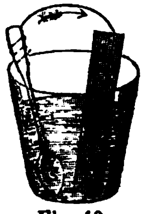


Fig. 40.

4. This experiment fully illustrates *the electrotype process.*

Exp. 6. Place a slip of copper C (see Fig. 41) in a glass containing

hydrochloric acid; into the same glass insert a strip of zinc Z; so long as the metals remain apart, no chemical action can be seen, and no electricity is developed; bring the upper extremities *d* of the metals into contact; active decomposition immediately begins; the chlorine combines with the zinc, and the hydrogen, set free, makes its appearance at the surface of the copper in the form of minute bubbles — voltaic electricity is in action. Withdraw the extremities of the metals from each other; the electrical circuit is broken — electrical action no longer exists; restore the contact, and the electrical action is again renewed.

Fig. 41.

The disengagement of electricity is always in proportion to the chemical action; and the metal which is most acted upon by the fluid gives off its negative fluid to the other plate, and the consequence of this is, that the current proceeds from this latter plate to the former. In the experiment just given, the zinc plate is acted upon by the acid, and the voltaic current proceeds from the upper extremity of the copper plate to the zinc plate, as shown in the figure.

The cheapest acid for generating small portions of voltaic electricity with zinc and copper plates is sulphuric acid, diluted with about twelve parts of water to one of the strong acid.

Exp. 7. Bend the zinc Z as shown in Fig. 42; place a bit of blotting paper, moistened with iodide of potassium, upon the zinc at A; bring the extremity B of the strip of copper C (or platinum) in contact with the moistened paper; the current of the electric fluid passes in the direction of the arrow; the iodide of potassium is decomposed by the electric current; the iodine is evolved at the positive pole, and the alkali, free potassa, at the negative pole.

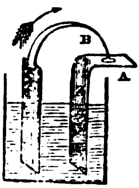


Fig. 42.

The experiment will be more striking if a drop of a solution of starch be also added to the moistened paper.

Exp. 8. Perform the same experiment with the bibulous paper moistened with prussiate of potassa, slightly acidulated with hydrochloric acid.

Exp. 9. Twist a piece of copper wire, in the form of a spiral or helix, round a small glass tube; connect the extremities of the wire with the zinc and copper plates immersed in diluted sulphuric acid; insert a steel needle into the glass tube; after a short time, the needle will be found to be powerfully magnetic.

Exp. 10. Bend a piece of soft iron wire H into the form of a horseshoe magnet; twist a piece of copper wire, covered with silk or cotton, round this wire, as shown in Fig. 43; connect the extremities of this

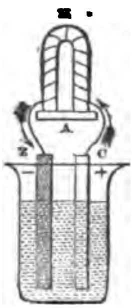


Fig. 43.

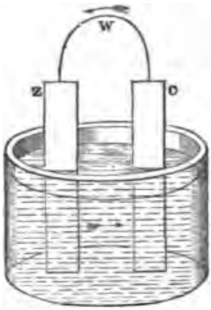


Fig. 44.

wire with the voltaic plates Z and C; the horseshoe wire H instantly becomes a magnet. If you have no covered wire at hand, wrap a piece of paper round the horseshoe wire before you twist the copper wire round it.

Exp. 11. Place the copper wire C Z, connecting the voltaic plates, in the plane of the magnetic meridian; bring a magnetic needle exactly over the wire C Z; the needle will be deflected from its north and south direction by the action of the wire C Z, conducting the voltaic current: now bring the needle exactly below the wire C Z; the needle will be deflected to the side opposite to that towards which it was before deflected.

BATTERIES AND THE DIRECTION OF THE VOLTAIC CURRENT.

5. Fig. 45 represents a single pair of zinc and copper plates acted upon by a diluted acid; the connecting wire C Z shows the direction of the electric fluid; that portion of the copper plate which is immersed in the acid becomes charged with negative electricity, and, as a necessary result of the law of electrical repulsion, the positive fluid is driven off from the upper extremity; hence the direction of the current. In all batteries, the current will always proceed from the wire attached to the metal least acted upon by the decomposing fluid.

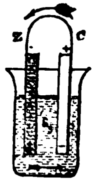


Fig. 45.

In Volta's battery, represented in Fig. 39, of which all

other batteries may be regarded as mere modifications, the wire P attached to the last copper plate will be a positive or + pole, and the wire Q attached to the first zinc plate will be a negative or — pole.

Fig. 46 represents a voltaic arrangement of two plates Pt., Pt., of the same metal, viz., platinum, immersed in different fluids, — A an alkali, and *c* concentrated nitric acid, separated by a porous partition *a b*. The platinum immersed in the alkali becomes positively electrified, and that in the acid negatively electrified, and the current flows as shown in the figure.

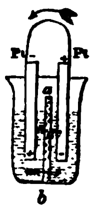


Fig. 46.

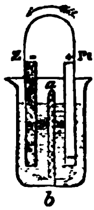


Fig. 47.

Fig. 47 shows the voltaic action which takes place when different metals are immersed in different fluids. The platinum plate Pt. is immersed in concentrated nitric acid M, and the zinc plate Z in concentrated sulphuric acid S, the two acids being separated from each other by the porous partition *a b*. In this case, the most intense electromotive tension is excited, the one metal being immersed in that fluid which renders it most powerfully negative, and the other metal in that fluid which renders it most powerfully positive. This is the principle upon which Groove's battery acts, which is certainly the most powerful that has yet been constructed.

DIFFERENT FORMS OF THE VOLTAIC BATTERY.

6. *Cruickshank's battery*, represented in Fig. 48, consists of an oblong trough of baked wood, divided into cells, to be filled with acid, by a number of pairs of rectangular plates of zinc and copper. This form was a decided improvement on the common pile, but still it had several inconveniences in practice.

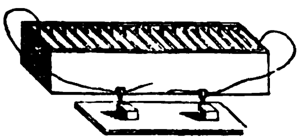


Fig. 48.

The arrangement represented in

Fig. 49 removed many of these inconveniences. It is merely a slight modification of the Couronne de Tasses, represented in Fig. 39. The trough T, with its cells, is made of wedgewood ware; the plates of zinc and copper, forming each pair, are soldered together by a connecting

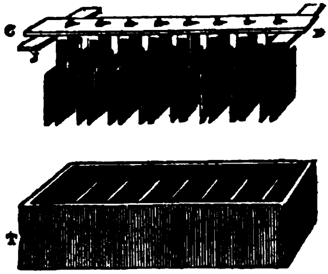


Fig. 49.

rod at the top, leaving them sufficiently apart at the bottom to span the partitions of the trough. The plates, thus joined in pairs, are all attached to a wooden bar C D, by which they may be readily let down into the trough, when they are required to be in action, or withdrawn from the trough when the action is to be suspended.

The greatest advantage attending this arrangement is, that by simply raising the plates, the fluid may remain in the trough while the action of the battery is suspended.

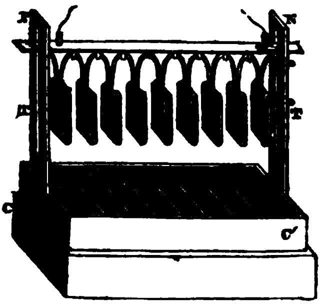


Fig. 50.

Wollaston's battery. — Wollaston, having discovered that the effect of the foregoing battery was augmented by increasing the surface given to

the copper, he enveloped the zinc plate of each pair with the copper plate of the preceding one, taking care, at the same time, to avoid all metallic contact between these two plates. By this arrangement, the copper plate has double the surface of the zinc plate.

Fig. 51 represents a more convenient form of this battery, where the trough is replaced by a series of glass jars. The acid can be more easily

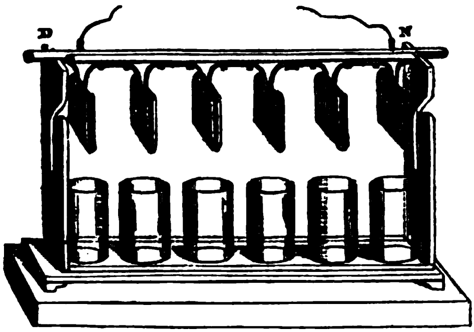


Fig. 51.

changed or discharged from these separate cells than from the cells in the trough of the preceding form of the apparatus.

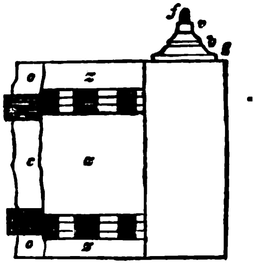


Fig. 52.

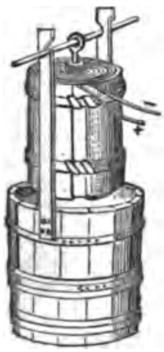


Fig. 53.

The helical battery. — In this battery, the zinc and copper are wound into the form of a helix, and plunged into a glass vessel containing the

diluted acid; the helix of the zinc, in each pair, must not be in metallic contact with that of the copper; but the helix of zinc in one vessel must be in metallic communication with the helix of copper of the succeeding pair, and so on, as in Wollaston's battery. Fig. 52 shows the manner of forming each pair of helixes, and Fig. 53 the trough adaptation for each pair. This arrangement presents a great surface of metal in each pair to the action of the acid, without the necessity of having very large troughs. The acid mixture for charging this battery is, water mixed with one fortieth in volume of strong sulphuric acid and one sixtieth of nitric acid.

The batteries hitherto described all have one decided inconvenience, viz., that after a short time they lose their power, which occasions them to act with a variable force during the same course of experiments. The zinc plates soon become covered with sulphate of zinc, and the copper plates with hydrogen and even oxide of zinc; these deposits not only greatly reduce the power of the battery when in use, but also require the plates to be cleaned before being put into action again. In order to avoid these inconveniences, Daniell, Grove, and Bunsen invented their constant batteries.

CONSTANT BATTERIES.

7. These batteries are constructed on the principle explained in connection with Fig. 47, p. 309; where the porous partition, without interrupting the conduction of the voltaic fluid, prevents the accumulation of depositions upon the plates.

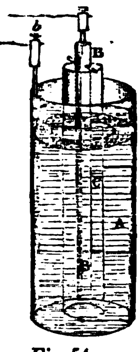


Fig. 54.

Daniell's constant battery. — A single pair of this battery is represented in Fig. 54. A is a copper vessel; C a porous cell, into which is inserted a cylinder of amalgamated zinc B; *a* and *b* are binding screws for connecting the respective metals with others in the series, or for attaching conducting wires when a single pair only is to be used. The cell C into which the zinc dips is filled with diluted sulphuric acid, (one of strong acid to about twenty of water;) and the copper vessel A is filled with a saturated solution of sulphate of copper. So long as the poles *a* and *b* are disconnected, no action will take place; but the moment the circuit is completed by connecting the screws *a* and *b*, a very powerful action occurs; the inner surface of the copper vessel becomes gradually covered with a layer of pure copper, and the porous cell C becomes

charged with sulphate of zinc. This process tends to deprive the solution of sulphate of copper of its copper, and to neutralize the sulphuric acid by the dissolution of the zinc; in order, therefore, to sustain the action unimpaired, some crystals of sulphate of copper are placed upon a perforated shelf *c*, in contact with the solution.

Fig. 55 shows the manner in which a series of these cells are connected so as to form a battery.

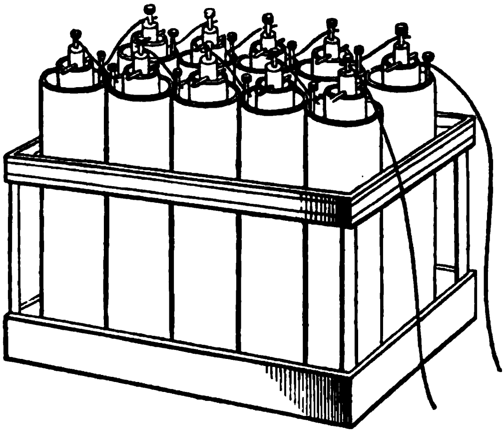


Fig. 55.

The advantages of this battery are as follows: (1.) The solution of the zinc is kept apart from the copper by the porous cell. (2.) The hydrogen, instead of escaping, as in the ordinary batteries, combines with the oxygen of the oxide of copper, and precipitates pure copper upon the side of the copper vessel, and does not in the slightest degree affect the action of the battery. (3.) There are no noxious fumes arising from the action of the battery. (4.) The amalgamation of the zinc, without at all affecting the production of electricity by the battery, prevents the zinc from being dissolved by the sulphuric acid when the battery is not in use — that is to say, when its poles are not united by a conductor; but the moment this union takes place, the zinc is attacked by the acid just as if the mercury were not there, only the oxide that is formed does not adhere to the surface of the metal, which it would do if the zinc were not amalgamated, and would thereby tend to weaken the action of the battery. Plates of zinc are very easily amalgamated by pouring mer-

cury upon the zinc, and at the same time rubbing it on the surface with a piece of chamois leather dipped in diluted sulphuric acid, which cleans the surface of the zinc, and thereby brings the mercury and zinc into combination.

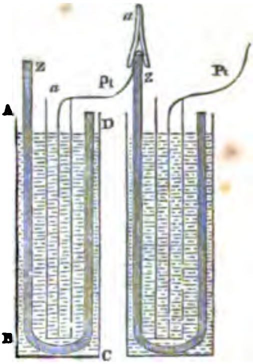


Fig. 56.

Grove's battery. — This battery is constructed on the same principle as Daniell's; that is to say, the plates are acted upon by two liquids separated from each other by a porous earthen ware partition. The pairs of plates are composed of amalgamated zinc Z and platinum foil P*t*, plunged into a cell A B C D composed of glazed porcelain or glass. The cell A B C D is filled with diluted sulphuric acid, which acts directly upon the zinc; and the porous cell *a* into which the platinum is plunged is filled with nitric acid. The platinum plate P*t* is in metallic contact with the zinc of the succeeding cell, as shown at *a;* and so on to the whole series of cells in the battery. As the power of these batteries is much increased by giving to the zinc plates a very large surface as compared with the surface of the platinum plates, the zinc plates are bent round the porous cell *a*, so that they form in each cell two vertical surfaces united by a horizontal surface at the bottom.

When the poles of this battery are united, so as to bring it into action, the hydrogen arising from the decomposition of diluted acid does not attach itself to the platinum, but goes to change the nitric acid into nitrous acid; the oxide of zinc remains, as in Daniell's battery, in the cell of the diluted acid, without penetrating through the porous cell to the platinum, which consequently remains perfectly clean; this circumstance essentially contributes to keep up the power and constancy of the battery, which render it so valuable as a voltaic combination. After a time, however, the nitrous acid, which is constantly formed, acquires a high temperature, and gives off deleterious fumes; when this takes place, the action of the battery should be arrested. This battery, for almost every purpose, is the most powerful that has yet been constructed. About half a dozen cells, with a platinum surface in each of ten square inches, will be found sufficiently powerful for performing all the most interesting experiments connected with voltaic electricity.

Bunsen's battery differs from Grove's only in charcoal being substituted for the platinum. The cells of this battery have the cylindrical form,

represented in Fig. 57, in consequence of the carbon or charcoal being best made in the form of hollow cylinders. The strip of copper A B

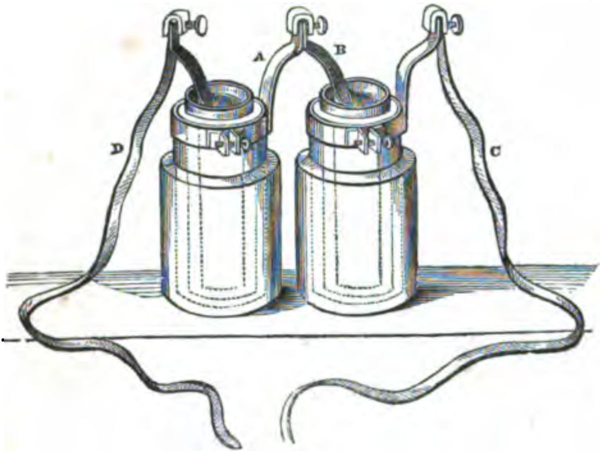


Fig. 57.

shows how the zinc of one cell is united with the carbon cylinder of the succeeding cell; and so on. The figure also shows how the strips of copper C and D forming the poles of the battery are connected with the extreme cells of the battery.

Each charcoal cylinder usually carries a collar of copper at its upper end for the purpose of fixing the connecting strip of copper to it; this

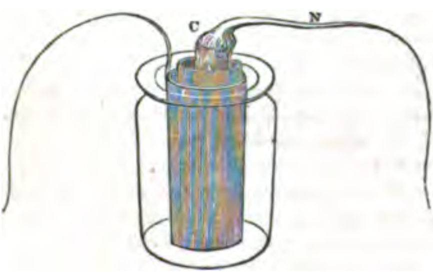


Fig. 58.

copper stands above the glass vessel so as not to come in contact with the nitric acid; however, it is found that, owing to the porous nature of the charcoal, the acid, to a certain extent, rises to the copper collar, and in time destroys its efficiency. The following contrivance (see Fig. 58) completely remedies this inconvenience: the charcoal cylinder C is solid; and into its top is thrust a stout copper rod N M, which is bent so as to be brought into contact with the succeeding zinc cell. To prevent the acid ascending to this copper rod, the top of the charcoal cylinder surrounding the wire is covered with a cement of wax.

It is almost unnecessary to say that the charcoal cylinder in this battery is plunged into the nitric acid, filling the porous tube or cell, and that this porous cell is placed within the cylinder of amalgamated zinc, which is surrounded by the diluted sulphuric acid filling the glass jar or porcelain vessel.

Smee's battery. — In this battery, the plates are acted upon by only one liquid, viz., diluted sulphuric acid, (one part of acid to about seven parts of water. Fig. 59 represents one of the cells of this battery. A the earthen ware cell filled with the diluted acid; Z Z two vertical plates of amalgamated zinc, one on each side of the platinized plate of silver S; *w* a bar of wood, to which these plates are fixed; *b* a binding screw, which secures the zinc plates to the wooden bar. The connections are made, as usual, by means of the small binding screws shown in the figure. This forms a highly economical and efficient battery. Although its power may be less than Grove's battery, at the same time it is in many respects more convenient and agreeable for general use, especially for conducting experiments relating to electro-magnetism.

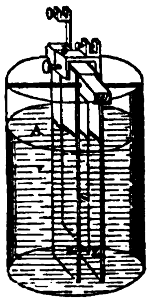


Fig. 59.

VOLTAMETERS.

8. These instruments are used for measuring the power of a battery. There are three kinds of voltameters at present in use; one of them depends upon the decomposing power of the battery, another upon its heating power, and the third upon its magnetizing power.

It has already been shown how the poles of a battery resolve water into its constituent gases — hydrogen and oxygen. Now, it is presumed that this decomposing power of a battery is in proportion to its general power, or rather in proportion to the quantity of electric fluid developed by the battery. Now, in the gas voltameters represented in Figs. 60, 61, and 62, the quantity of gas liberated by the poles of the battery in a given time is taken as the measure of the power of the battery; or, what amounts to the same thing, the power may be measured according to the inverse ratio of the time requisite for liberating a given volume of the gas.

In Fig. 60, the platinum poles of the battery are placed vertically in a graduated glass tube D, very near to each other; the lower extremities

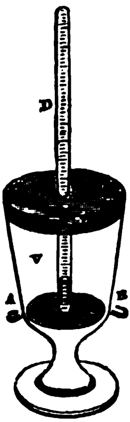


Fig. 60.

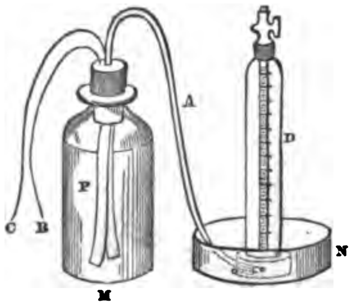


Fig. 61.

A and B come out at the bottom vessel V containing the water, so that a connection may be readily made between them and the wires leading

from the extreme plates of the battery. The two gases in this instrument are received in the same tube; they may, however, be received in separate tubes, as in the instrument represented in Fig. 37; but in this case, the platinum poles, being at a greater distance from each other, cause the decomposition to go on more slowly. When the battery has very great power, the gases are usually collected in a graduated receiver D (Fig. 61) placed upon the pneumatic trough N; the decomposition of the water takes place in a bottle M fitted up with a cork and bent tube A for conveying the gases to the receiver D; the platinum poles or electrodes P, hanging near together within the bottle, are connected with the wires B and C leading to the extreme plates of the battery.

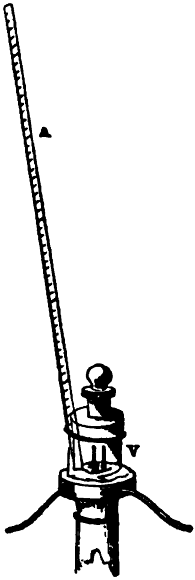


Fig. 62.

Fig. 62 represents an eligible form of this apparatus, when the liberation of gas is very feeble. The quantity of gas is measured by the amount of displacement of the liquid. A graduated tube A proceeds laterally from the lower part of the vessel V wherein the decomposition of the water is carried on; so that, as the gases rise to the top of the closed vessel V, an equal volume of water is thrown up the tube A.

The three following voltameters depend upon the calorific effects of the battery.

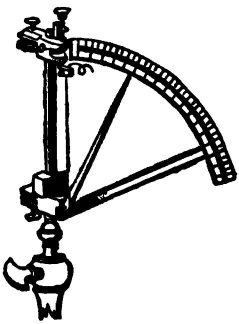


Fig. 63.

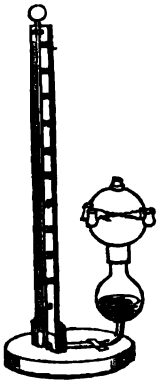


Fig. 64.

Fig. 63 represents a voltameter, which is merely a slight modification of the common pyrometer. The platinum wire *a b* forming a portion of the voltaic circuit becomes powerfully heated, and expands, and allows the pointer *a d* to fall; the graduation on the quadrant indicates the amount of expansion, and consequently the relative power of the battery.

Fig. 64 represents a still more sensible voltameter, in which the platinum wire forming a portion of the voltaic circuit passes through the ball of an air thermometer; the expansion of the air by the heat of the wire causes the liquid to rise in the vertical graduated tube; and so on.

The magnetic voltameter will be hereafter fully described.

EFFECTS OF VOLTAIC ELECTRICITY.

CHEMICAL EFFECTS.

9. The chemical action of voltaic electricity upon different substances placed in the circuit forms one of its most important and remarkable features. It has been shown that frictional electricity exerts a chemical action; but it is very feeble as compared with that which even small voltaic batteries exert.

One of the most remarkable facts connected with these decompositions is, that certain elements, into which the substances are resolved, always arrange themselves on the positive pole or electrode, and certain other elements always arrange themselves on the negative pole or electrode. Thus oxygen, chlorine, iodine, and the acids always fly to the positive pole of the battery; and hydrogen, alkalies, oxides, &c., always fly to the negative pole. For example, in the decomposition of water, (see page 304,) the oxygen is accumulated in the tube placed over the positive pole, while the hydrogen is accumulated in that placed over the negative pole. This fact has led to the formation of a system of *electro-chemistry*. The respective poles are supposed to be in a contrary electrical state to the elements which they attract; hence oxygen, chlorine, acids, &c., are negative elements, and alkalies, oxides, &c., are positive. Every chemical compound, therefore,

consists of a negative element and a positive element, which are held united by the law of electrical attraction.

Exp. 1. *Decomposition of water.* — This is most successfully performed by the apparatus described at page 304; but the following simple form of making the experiment is highly instructive.

Immerse a strip of amalgamated zinc and a strip of clean copper into a glass of water slightly acidulated with sulphuric acid: so long as the metals are kept apart, no action can be observed; but the instant that the upper extremities of the metals are brought into contact, the water is decomposed, numerous little bubbles of hydrogen collect round the copper, and the oxygen at the same time passes to the zinc, and oxidizes it.

Exp. 2. *Decomposition of neutral salts.* — Fill the two tubes of the apparatus represented in Fig. 37, page 304, with a solution of sulphate of soda, or any other neutral salt, colored blue with tincture of violets; then, when the battery is in action, the acid will be attracted to the positive electrode, and will render the liquid in the tube red, and the alkali will be attracted to the negative electrode, and will tinge the liquid in the tube green; transpose the poles, and the effects will be reversed.

Exp. 3. *To precipitate a metal from the solution of a metallic salt.* — Fig. 65 represents a simple piece of apparatus for producing this decomposition. *a* is a glass tube about an inch in diameter, having a piece of bladder tied over its lower extremity, and suspended in a large glass vessel *b*; pour a solution of acetate of lead (sulphate of copper, nitrate of silver, &c., will answer the purpose) into the glass tube *a*; fill the outer vessel with diluted sulphuric acid; into the solution of lead immerse a platinum wire *p*, and into the diluted sulphuric acid plunge a strip of amalgamated zinc Z, in metallic contact with the platinum; then a voltaic circuit will be formed, consisting of two metals and two exciting fluids; the acetate of lead will be decomposed, the metallic lead will be attracted to the platinum, and the acid to the zinc.

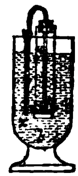


Fig. 65.

The metallic vegetations called the *lead tree*, &c., depend upon the voltaic action.

Exp. 4. Connect the tin foil plate G with the copper pole of a small battery, and the metal plate D with the zinc pole of the battery. Lay a piece of white blotting paper, soaked in a diluted solution of hydrochloric acid and prussiate of potassa, upon the plate D; draw a number of strokes with a brush dipped in varnish across the plate G, as shown in Fig. 66; take a bent wire A, and connect the two

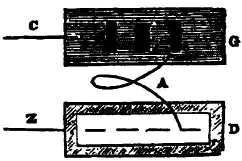


Fig. 66.

plates with it; move the wire from end to end; then the electro circuit will be complete whenever the wire connects the metallic foil and the damp paper, and the circuit will be broken at those parts where the wire passes over the varnish; the solution on the paper will be decomposed at the former parts, but will remain unchanged at the latter parts, as will be shown by the deep-blue marks formed upon the paper by the decomposition of the prussiate of potash.

This experiment illustrates the principle on which the *copying electric telegraph* is constructed.

Electrotyping.

10. The decomposition and reduction of metals, in a state of solution, by the voltaic battery, has led to some important discoveries in the arts — such as electrotyping, electroplating, &c.

The experiment given in connection with Fig. 49, page 310, is a familiar example of electroplating; electrotyping depends upon the same principle.

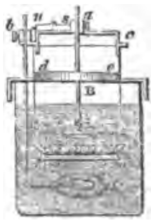


Fig. 67.

Fig. 67 represents a very simple contrivance for obtaining small electrotype casts. A is a glass vessel, in which the mould from which the cast is to be obtained is placed. B is a glass tube suspended within the vessel A by means of a metallic ring *d e*, to which are fixed three strips of metals. The lower end of this tube *m n* is closed by tying a piece of bladder over it. The strip of brass *b c* has two binding screws *b* and *a*, by which the wires *a* Z and *b k* are secured; the lower extremities of these wires carry the substances Z and *k*, which act as the electromotors or voltaic plates constituting the simple battery. Z is an amalgamated zinc plate, suspended within the tube; *k* is the body from which the cast is to be taken, laid on the spiral-shaped extremity of the wire *b k;* the model is the negative electromotor, and Z the positive electromotor. The large glass A contains a concentrated solution of sulphate of copper; this is always kept in a saturated state by having crystals of sulphate of copper suspended in it; the tube B is filled with diluted sulphuric acid; the liquids should stand at the same level in both vessels. According to this arrangement, the electric current passes from the zinc Z to the mould *k;* and pure metallic copper is deposited upon the surface of the mould, and in time forms a complete cast of the surface.

The following particulars should be attended to in making electrotype

casts: The surfaces of the originals should be good conductors, and they should not contain any substances which would be acted upon by the sulphate of copper. The model may be of gypsum, wax, or any similar non-conducting substance, provided the surface of the model be covered with a metallic coating; plumbago dust or bronze powder, laid on with a camel's hair brush, forms a very good coating. A wax impression should be first slightly moistened with alcohol, and then the black lead should be rubbed over it with a stiff brush; the copper wire should then be warmed and pressed into the margin of the wax; the connection between the wax and wire should then be made with the black lead. A coating of wax dissolved in turpentine will protect any part of a coin from any metallic deposit. In every electrotype cast, the elevated portions of the original will be depressed, and *vice versa*; in order, therefore, to obtain exact fac-similes of the original, the first cast must be used as a matrix, on which the coating of copper must be thrown by the electrotype process.

Fig. 68 represents a more convenient arrangement. *z* is the amalgamated zinc rod, suspended in the porous cell *p*, which contains the diluted sulphuric acid; *c* the glass or earthen ware vessel containing the solution of sulphate of copper; *w* the copper wire connected with the zinc by a binding screw, and carrying at its lower extremity the seal or mould *m*.

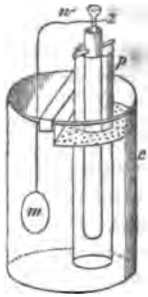


Fig. 68.

Fig. 69 represents another arrangement, where the current is generated in a distinct battery A; B is a distinct vessel for conducting the electrotype process. *m* is a metal rod for supporting the moulds, and *c* another rod supporting copper plates, which form the positive electromotors; *x* connects the moulds with the zinc in the battery, and *z* connects the copper plates with the copper

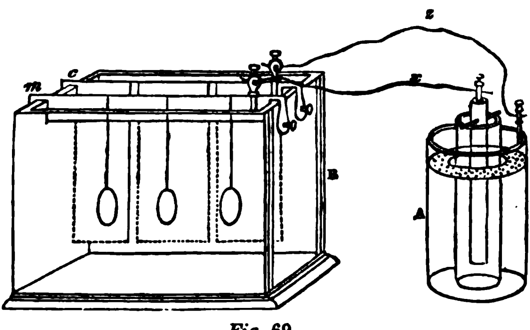


Fig. 69.

plates of the battery. The vessel B contains two parts of saturated solution of sulphate of copper and one part of sulphuric acid diluted with about seven parts of water. The action which takes place is simply as follows: the copper is consumed from the plates *c*, and deposited on the moulds *m*; so that the copper solution in the vessel B remains unchanged in its strength from the commencement to the close of the process.

ELECTROPLATING EXPERIMENTS.

11. *Exp.* 1. Place a small plate of clean platinum foil in a saucer, and pour over it a solution of sulphate of copper, covering it to the depth of about a sixteenth of an inch; touch the platinum plate with a pointed strip of bent zinc, the other end of which is kept in the liquid; different colored rings of metal will be formed upon the platinum plate.

Exp. 2. The brilliancy of the depositions will be much increased by using a constant battery of three or four pairs of cells.

PROTECTION OF METAL PLATES BY VOLTAIC CURRENTS.

12. Voltaic currents not only affect combinations and decompositions, but they may also be employed for impeding or arresting certain decompositions which would otherwise take place by the ordinary laws of chemical affinities. Thus, for example, Davy protected the copper bottoms of ships from the corrosion of the salt water by connecting plates of zinc with the copper sheathing. In order to protect a metal from the chemical action of an acid or a saline solution, it is only necessary to combine the metal with some other metal in the fluid, which shall act as the positive electromotor.

Exp. 1. Place a copper plate in a saucer; pour some diluted sulphuric acid upon it: then the metal will be violently acted upon by the acid; now touch the copper with a strip of zinc, and the action on the copper will be instantly arrested; the action will now be transferred to the zinc, and the copper will remain unaffected by the acid, until the whole of the zinc be dissolved.

LUMINOUS AND HEATING EFFECTS OF VOLTAIC ELECTRICITY.

13. The most brilliant of all the effects of voltaic electricity is the arch of electrical light evolved between two charcoal points. This phenomenon may be exhibited with about a dozen pairs of Grove's or Bunsen's battery. This experiment may be most conveniently performed by

Fig. 70.

fixing charcoal points (pieces of graphite answer best) to the rods of a universal discharger. The poles of the battery are respectively connected with the extremities of the rods, as shown in Fig. 70, where the arch A B represents the form of the voltaic light. The points must be first brought into contact with each other, and then gradually withdrawn until the arch attains its most brilliant appearance; the length of the arch of course varies with the power of the battery; that is, with batteries of average power, from three quarters of an inch to about an inch and a half. This arch of flame is not produced by combustion, for it may be exhibited with equal brilliancy in a vacuum, and even takes place under water.

The intense heat of this electric arch will ignite the most refractory substances.

Exp. 1. Amalgamate the ends of the polar wires; bring them near together, while the battery is in action; a white starlike spark will be seen, accompanied with a crackling noise similar to the emission of a feeble spark of frictional electricity.

Exp. 2. The spark obtained from these amalgamated points may be seen under water, or in the flame of a candle.

Exp. 3. Immerse one of the wires into mercury, and bring the end of the other wire near the surface of the fluid; a spark is emitted just before the wire touches the mercury, leaving a small black speck upon its surface.

Exp. 4. Coat the ends of the polar wires with soot, by holding them for a short time in the flame of an oil lamp; the sparks obtained from these coated wires will be much stronger and brighter.

The power of a voltaic battery, as we have already shown, is roughly estimated by the heat which it produces in a given conducting wire. The temperature to which a conducting

wire will be raised by a battery, depends upon the length and thickness of the wire, as well as upon the nature of the metal, whether or not it is a good or a bad conductor of electricity. Short fine wires become most heated, and of all metallic wires, platinum, being the worst conductor of electricity, becomes most powerfully heated by conducting the electric fluid.

The calorific effect appears to depend more upon the size of the plates than upon the number of pairs; that is to say, it depends upon the quantity of the electric fluid evolved, rather than upon its intensity or tension.

The calorific effects of the voltaic battery may be most conveniently shown, by stretching the wires to be heated between the extremities of the rods of the universal discharger. (See Fig. 70.)

Exp. 1. To show the heating power of a battery. Stretch a piece of fine steel wire between the poles of the battery; the wire, if it is not too long, will instantly become powerfully incandescent. If, on the first trial, the wire only presents a dull heat, gradually reduce the length of the wire, until it glows with a white heat; reduce the length of the wire a little more; then it will be first fused, and then ignited.

The same experiment may be performed with platinum or silver wire.

Exp. 2. Ether, alcohol, phosphorus, gunpowder, &c., may be readily ignited by making the hot platinum connecting wire to pass through them, or to touch some portion of them.

Exp. 3. If the platinum wire be conducted through a small portion of water, it will speedily boil.

PHYSIOLOGICAL EFFECTS OF VOLTAIC ELECTRICITY.

14. The relation between voltaic action and the nervous system of animals was very carefully investigated at a very early stage of the history of voltaic electricity.

The peculiar nature of this relation is explained at page 303, when a small battery is employed. But with large batteries the effects are truly surprising. Dr. Ure thus describes his experiments upon the body of a full-grown man, fifteen minutes after death. Upon applying one of the polar wires to the forehead, and the other to the heel, every muscle

in his countenance was simultaneously thrown into fearful action; rage, horror, despair, anguish, and ghastly smiles united their hideous expression in the murderer's face. At this period, several of the spectators were forced to leave the apartment from terror and sickness, and one gentleman fainted.

The physiological effects of voltaic electricity appear to depend upon intensity, rather than upon quantity; that is to say, upon the number of pairs in the battery, rather than upon their extent of surface.

The effect of the voltaic shock is much increased by attaching copper cylinders to the extremities of the conducting wires, and also by dipping the hands, by which the shock is received, in water slightly acidulated.

The magnetic effects of voltaic electricity are so various and interesting, that they have been treated as a distinct branch of electrical science, called *Electro-Dynamics.*

ELECTRO-DYNAMICS.

ELECTRO-MAGNETISM.

1. It has already been shown (Exp. 9, p. 307) how a steel needle may be magnetized by passing a voltaic current through a wire helix. When a helix is wound to the right, or in the direction of a corkscrew, it is called a *right-handed* helix, as shown in Fig. 71, and when the helix is wound in

Fig. 71.

Fig. 72.

the contrary direction, that is, to the left, it is called a *left-handed* helix, as shown in Fig. 72. Helix wires should be formed of copper wire, covered with silk, for the purpose of insulating them.

When a needle is magnetized by a current passing through a right-handed helix, or a corkscrew helix, the south pole of the needle is always at the extremity through which the currents enter; that is to say, at the extremity that is in connection with the positive electricity. On the contrary, when a needle is magnetized by a *left-handed helix*, the north pole is at the extremity which is in connection with the positive electricity.

These facts are in exact accordance with Ampère's theory of magnetism, (see p. 301;) for the electric current moves round the magnetic bar in precisely the same manner as the magnetic current is supposed to do in that theory, thereby showing that the electric current which induces the magnetic condition is equivalent to the magnetic current upon which the ordinary magnetic condition is supposed to depend.

Let S N (Fig. 73) be a right-handed helix, that is, a corkscrew helix,

through which the electric current enters at S, and passes out at N; then, from what has been said, the helix will become a magnet, having the extremity S for its south pole, and N for its north pole. This may be tested experimentally by using *De la Rive's floating battery.* The extremities of the helix are connected with zinc and copper plates Z and C, fixed in a piece of cork, so as to make the whole apparatus to float in a strongly acidulated liquid. This float battery, like the floating needle, will place itself in the north and south direction of the needle; the extremity S, through which the current enters, will be directed to the south.

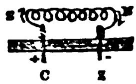


Fig. 73.

The author has found the following form of this apparatus to be very convenient in practice.

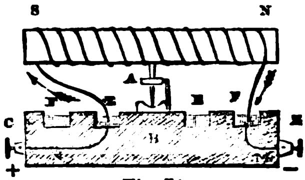


Fig. 74.

B is a deal board, having two concentric grooves E and F cut in it, and filled with mercury; the wires N and M connect the mercury in these grooves with the binding screws C and Z, to which the poles of the battery are attached; S N is a corkscrew helix surrounding a soft bar of iron; one extremity of the wire dips into the mercury of the groove F, and the other into that of the groove E; the soft iron bar, with its helix, turns upon the pivot A. When the positive pole of the battery is fixed to the binding screw C, and the negative pole to the binding screw Z, the helix, with its soft iron bar, becomes an actual magnetic needle, and will settle itself in the direction of the magnetic meridian, the extremity S being directed to the south, and the other extremity N to the north.

If the soft iron bar be taken away, and a steel needle be inserted in its place, the needle will be magnetized, having the extremity towards S a south pole, and the extremity towards N a north pole.


Fig. 75.

Fig. 75 represents another form of the floating battery, where the copper and zinc plates are immersed in a glass tube, filled with the diluted sulphuric acid, and the whole is made to float in a vessel of water.

Electro-magnets of immense power may be formed by voltaic helices.

The Electro-Magnet, or soft iron Horseshoe Magnet.

2. Fig. 76 represents an electro-magnet; M is the soft iron bent in the form of a horseshoe magnet; P and N are the extremities of the helix of covered copper wire, surrounding the bar in the manner just described; K is the keeper of the magnet, from which a heavy weight may be suspended, to show the power of the magnet. When the extremities, P and N, are connected with the poles of a single pair of any of our constant batteries, the soft iron instantly becomes a very powerful magnet, capable of supporting a weight of 1 cwt. to about 1 ton. The moment the connection is broken, the magnet loses its power. The wire intended to form the coil is cut into several portions, and is coiled separately on the iron, and then all the corresponding extremities are collected into parcels, which are soldered to a thick wire, which communicates with the pole of the battery. By this arrangement, the current is divided into a series of short branches, which, collectively, communicate with the poles of the battery by a short, strong wire; this gives energy to all the coils, and thereby increases the power of the electro-magnet.

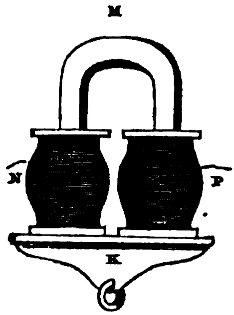


Fig. 76.

These temporary magnets have been called *electro-magnets*, to distinguish them from permanent steel magnets, and *electric helices* just described.

Rotating Magnets.

3. The rotating magnet, invented by Dr. Richie, is represented in Fig. 77. In this instrument, a permanent rotatory motion is given to an electro-magnet *c*, upon a vertical pivot, by means of the alternate attraction and repulsion of the poles N and S, of a permanent horseshoe magnet. In order to produce this continuous rotation, it is requisite that the poles of the electro-magnet should be reversed at every time they pass the poles of the permanent magnet; this is effected by a very simple and elegant artifice: *a b* is a wooden cup of mercury, divided into two compartments by a bridge or partition of wood, in a line with the poles N and S, whose upper edge is a little below the exterior edge of the cup; so

that when the two compartments are filled with mercury, the cohesion of the particles of the fluid causes it to stand a little higher than the level of the top edge of the partition; the two extremities of the helix dip a little into the mercury without reaching to the level of the top of the partition, so that the electro-magnet may freely revolve upon its vertical pivot; the mercury in one of the compartments is connected with the positive pole of a small battery, and the other compartment with the negative pole; by this contrivance, the poles of the electro-magnet are reversed at every time the dipping wires cross the partition, and, consequently, if the poles of the permanent magnet attract the poles of the electro-magnet in any given position, they will be repelled the moment the dipping wires have crossed over the partition, and thus the continuous rotation is sustained.

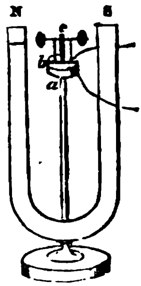


Fig. 77.

The following is a brief description of a rotatory magnet invented by the author some twenty years ago, and employed by him in an extended form as a magnetic engine, capable of yielding about a quarter of a horse power.

N S is the electro-magnet, turning upon a horizontal axis A B; N F and S E are the terminal wires of the coil; each of them forks off into two branches, F H, F J, and E K, and E G; the extremities of the wires are connected with metal segments. H, J, K, and G, attached to the ivory wheels A and B, fixed to the common axis A B; the circumferences of these segments are placed concentric with the axis of motion, and their edges dip into mercury placed in the cups L and M, which are connected with the poles of the battery: by this contrivance the poles of the electro-magnet are changed when one pair of segments passes out of contact, and another pair comes into contact, with the mercury in the cups. The opposite poles of a permanent magnet are placed in a line with the electro-magnet when its position corresponds with the change of its polarity, as in the case of Richie's rotating magnet.

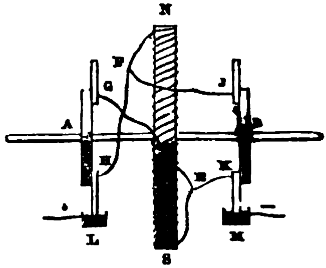


Fig. 78.

Contact Breakers. — Telegraphic Alarm Bell.

4. The two foregoing pieces of apparatus show how the poles of an electro-magnet may be reversed by changing the direction of the voltaic current. The contrivance represented in Fig. 79, called a contact breaker, shows with what rapidity an electro-magnet can acquire and lose its magnetism. M is a small electro-magnet, the armature of which, E, is capable of oscillating between the two poles of the magnet and a stop at its back, against which it is pressed by a spring. The conducting wire D coils round the lower branch of the magnet, as shown in the figure, and the other conducting wire C is attached to the stop, and then a wire passes from the foot of the oscil-

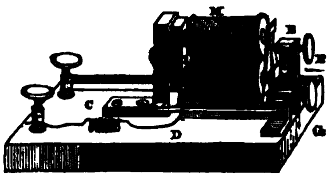


Fig. 79.

lating armature to the extremity of the coil passing round the upper branch M of the electro-magnet; so that the electric current is complete when the armature is in contact with the stop, and it is broken when this contact is destroyed. The consequence of this arrangement is, the electro-magnet attracts the armature, which breaks the circuit, and the magnetism instantly ceases; then the armature, being pressed back by the spring, returns and strikes the stop, which again completes the circuit and renews the magnetism; the armature is again attracted by the magnet, and so on with great rapidity. The adjusting screws F and G enable the operator to regulate the rapidity of the strokes.

To form this instrument into an alarm bell, it is only requisite to fix a hammer to the top of the armature E, and to place a bell within the striking distance.

Instruments for measuring the Force of Magnets.

5. *Method of contact.* — The following is a simple contrivance for estimating the suspensive force of an electro-magnet: N J S is the elec-

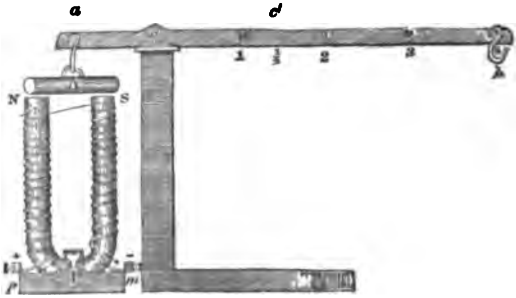


Fig. 80.

tro-magnet; *p* and *m* the binding screws to which the poles of the battery are fixed; A the feeder or armature, suspended from the extremity *a* of a graduated lever *a b* turning on a fixed centre or fulcrum *c*; *h* a sliding hook, to which a scale pan with weights may be attached. The weights, put in the scale pan, necessary for breaking the contact of the feeder A, give the data for calculating the force of the magnet, on the simple principle of the lever of the first kind.

Method of vibrations. — The oscillations of a magnetic needle, before it settles in its north and south direction, follow the same law as the vibrations of the pendulum. The directive force of a magnetic needle, therefore, may be measured by the number of oscillations that it will make in a given time when drawn a little to one side of its magnetic meridian. When the same needle is employed to determine the directive force at two different places on the earth, this directive force varies as the squares of the number of vibrations performed in a given time.

The vibration of the needle is also employed to determine the intensity of the different points in a magnetic bar. In this case, it is necessary that an allowance should be made for the directive force of the earth.

According to the experiments made by Coulomb, the attractive forces of the different points in a long magnetic bar, as estimated from the centre of the bar, increase in a geometrical progression as the distances from the centre increase in arithmetical progression.

TO MAGNETIZE STEEL BARS BY THE ELECTRO-MAGNETIC COIL.

6. The simplest way of doing this is to coil a very stout copper wire, covered with silk, round a pasteboard tube, about 18 inches long and 2 inches diameter. The bar A B to be magnetized is placed between two soft iron cores, A Q and B D, made exactly to fit the interior of the pasteboard tube E F. The whole is placed within the tube, and the extremities C and Z of the helix are connected with the poles of the battery: in a short time the steel bar A B will be magnetized to saturation.

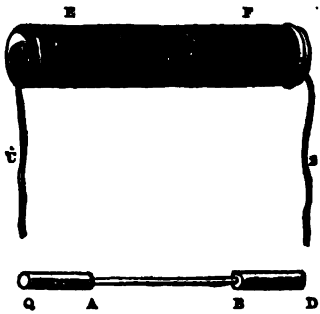


Fig. 81.

ON THE ACTION OF ELECTRIC AND MAGNETIC CURRENTS.

7. In addition to the magnetic effects of electrical currents, which have just been noticed, the following general laws of electro-dynamics have been established: —

General Laws of Electro-Dynamic Action.

a. Every metallic conductor, through which an electric current passes, acts on magnets suspended freely, and shows magnetic properties.

b. Electric currents exert on each other influences like those which they exert on magnets.

c. A magnet acts on an electric current precisely as another current would do.

d. Electric currents in conductors in like manner excite such currents.

e. Magnets can in like manner excite electric currents and the other electric influences dependent on them.

It must be observed, that the condition essential to these effects is, that the electric fluid must be in a state of motion, that is, it must be in the form of a continuous current; or, in other words, it must be in the condition which is called *dynamic*. There is no action when the electricity is in the *static* or *tension* state.

ACTION OF ELECTRIC CURRENTS ON THE MAGNETIC NEEDLE.

8. *Oersted's experiment.* — Place the conducting wire A B of a battery in the direction of the magnetic meridian, viz., B towards the north and A towards the south, as shown in Fig. 82; suspend a needle S N

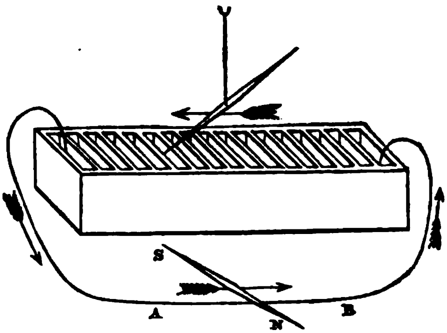


Fig. 82.

over the conducting wire A B, and the north pole N will be deflected to the east; suspend the needle *below* the conducting wire A B, and its north pole will be deflected to the west.

The needle, therefore, endeavors to assume a position perpendicular to the direction in which the electric current flows.

Ampère represented the action of the electric current on a magnetic needle under a form which is easily remembered. "We have only to conceive a man lying down in the portion of the circuit under consideration, in such a manner that the current enters by his feet, and goes out, consequently, by his head; furthermore, we have but to conceive that this man has always his face turned towards the needle, so as to look at it; then the action is always found to be such that the north pole of the

needle is deviated to the left of this man. This formula comprehends all possible cases."

It is easy to see that the positive current, coming from the positive pole of the battery, passes along the conductor, and arrives at the negative pole, and returns through the plates of the battery to the positive pole; so that the current has a different direction in the two parallel portions of the circuit, as shown in Fig. 82.

All these effects are perfectly in accordance with the theory of magnetic action explained at page 301. The needle seeks to place itself at right angles to the direction of the current, on the principle that the electric current in the magnet seeks to place itself parallel to the current in the wire.

Galvanometers.

9. We have explained the construction of certain voltameters or galvanometers depending upon the calorific and chemical effects of the voltaic current; but the most perfect instrument of this kind is that which depends upon the magnetic effects of the current.

The most simple magnetic galvanometer is represented in Fig. 83. A magnetic needle *n s* is suspended between two conducting parallel wires *w* and W, terminating in the mercury cups P and N. The conducting wire is placed in the direction of the magnetic meridian, so that the needle has the same direction as the wires. When the poles of the battery are inserted in the cups P and N, the needle is deflected after the manner described in the foregoing section. According to this arrangement, the conducting wire above the needle, as well as the wire below it, tends to deflect the needle in the same direction, so that the double wires exactly double the amount of deflection. The angle of deflection gives us a rough mode of estimating the quantity of voltaic fluid evolved by the battery.

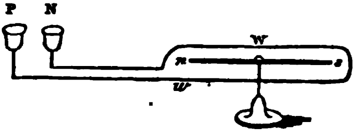


Fig. 83.

But, instead of bending the wire round the needle once, if we bend it twice, thrice, or any number of times, we must obviously increase the deflecting power in the same ratio. This construction is adopted in the galvanometer represented in Fig. 84; where *n s* is the needle, surrounded by a series of coils of covered silk wire, *a d d*. This instrument has been called the *galvanometer multiplier*.

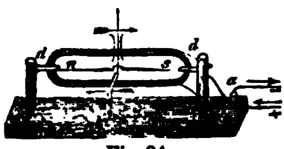


Fig. 84.

Fig. 85 represents a more elegant form of the instrument; where the coil of wire is wound round a wooden frame fixed upon a stand, and provided with binding screws.

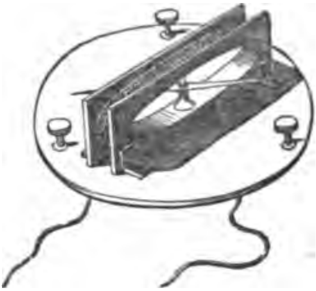


Fig. 85.

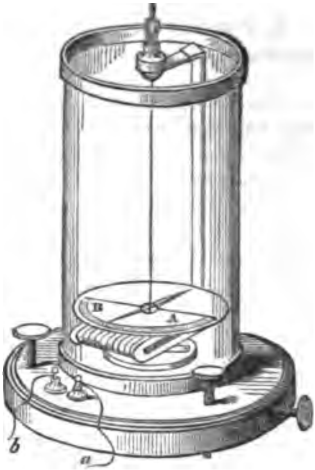


Fig. 86.

Nobili's galvanometer multiplier, represented in Fig. 86, consists of an *astatic needle* (see p. 300) suspended by a filament of untwisted silk, one of the needles being placed within the conducting coil, the other without it; so that the current of electricity tends to deflect both needles in the same direction, thereby giving a double power to the instrument. The whole of the coil, together with the needle and its thread of suspension, is covered with a glass shade; *a* and *b*, fixed to the binding screws, are the wires proceeding from the poles of the current, whose power is to be determined by the instrument; the extremities of the wire coil, of course, terminate in these binding screws.

ACTION OF ELECTRIC CURRENTS ON EACH OTHER.

10. Ampère discovered the following laws, according to which electric currents act upon each other:—

a. Parallel currents attract each other when they flow in the same direction.

Thus the parallel wires *a b* and *c d*, represented in Fig. 87, transmitting currents in the same direction, attract each other.

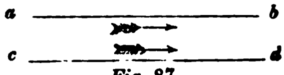


Fig. 87.

b. **Parallel currents repel each other when they flow in contrary directions.***

Thus the parallel wires *a b* and *c d*, represented in Fig. 88, transmitting contrary currents, repel each other.

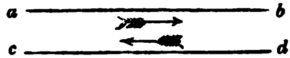


Fig. 88.

These laws are perfectly in accordance with the theory of magnetism explained at p. 301.

In order to establish these laws by experiment, the floating battery represented in Fig. 89 may be employed. This battery consists of a pair

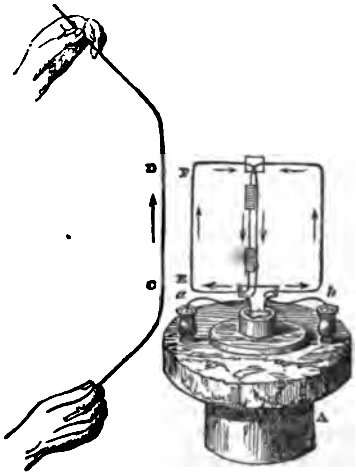


Fig. 89.

of plates, viz., platinum and amalgamated zinc, fixed to a cork float A, and having its poles in connection with the cups *a* and *b*; the wire frame proceeding from these cups conducts the current as represented by the arrows in the figure; the whole of this floating battery is placed in a vessel containing diluted sulphuric acid, which acts as the exciting fluid. To one of the vertical branches E F we present a parallel wire

C D, traversed by a powerful current of electricity; then when the currents flow in the same direction, the wire E F with its floating battery is attracted by the wire C D; and, on the contrary, when the current in the wire C D flows in a contrary direction, the floating battery is repelled.

The same laws hold true with respect to angular currents, or those currents whose directions are inclined to each other; the form of expression in this case being simply, that *currents which are directed to the same point, or which proceed from the same point, attract each other, and vice versâ, as before.*

VARIOUS MOTIONS PRODUCED BY THE MUTUAL ACTION OF MAGNETS AND CURRENTS, AND CURRENTS UPON EACH OTHER.

11. *The oscillating electrical spiral*, represented in Fig. 90, affords a beautiful illustration of the attraction of parallel currents. A fine flexible copper spiral wire A is suspended from the extremity of a conductor D, proceeding from the positive pole of the battery; the lower extremity of this spiral dips slightly into a cup of mercury, *a*, in which is placed the extremity of the wire C, leading from the negative pole of the battery. When the current is complete, the spiral vibrates longitudinally; for at every contraction the current is broken, and then the weight of the wire causes its extremity to sink again into the mercury, and thus a continuous oscillation is sustained.

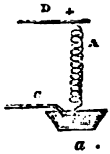


Fig. 90.

It has been shown that *a fixed or closed current exerts a tangential force upon the pole of a magnet which is free to move:* thus let A B, in Fig. 91, represent the direction of the fixed current, and N the pole of a magnet, free to obey the impulse; then the north pole N is impelled in the tangential direction N *n*; that is to say, in a direction perpendicular to the direction of the current A B.

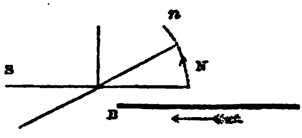


Fig. 91.

In like manner, since action and reaction are equal and contrary, a *pole of a magnet exerts a tangential force on a current which is free to move;* thus the pole N of a fixed magnet (see Fig. 92) will impel the free wire A B conducting a current in the tangential direction B *a*.

These results are generally represented in Fig. 93, where N represents the north pole of a magnet, C the section of the conductor of a descending electric current perpendicular to the plane of the paper; then the action of C upon N tends to move it in the direction N *n*, and the reaction of the pole N upon the wire C tends to move it in the contrary direction C *c*. If, therefore, the pole N be free to move round the wire C, the tangential line N *n* will be the direction of the motion; and if the conducting wire C be free to move round the pole N, the tangential line C *c* will be the direction of the motion.

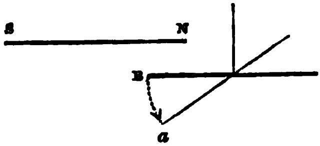


Fig. 92.

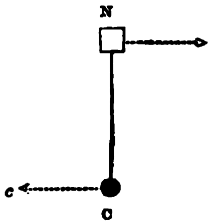


Fig. 93.

The following rotatory motions depend on these principles.

To make the pole of a magnet N *revolve round a fixed electric current* C.

This was first effected by Faraday in the following manner: A small magnet N is fixed to the lower part of a vessel V, by means of a silk thread; the vessel is filled with mercury nearly to the top of the magnet; C is a conducting wire dipping into the mercury, and Z is another conductor communicating with the mercury at the bottom of the vessel. Now, when the electric current is established, by connecting the extremities of the wires C and Z with the opposite poles of the battery, the pole N of the magnet revolves round the conducting wire C. The ends of the wires should be amalgamated to insure metallic contact. If the current is descending, that is, if C be connected with the positive pole of the battery, and if N be a north pole, its motion round the wire will be direct, that is, in the direction of the hands of a watch; and so on, *vice versâ*.

Fig. 94

To make a movable wire A B, *traversed by a current, revolve round the pole* N *of a fixed magnet.*

Here the wire A B is suspended from the wire C by a loop, and dips into the mercury in the vessel V; when the circuit is established, by

connecting the wires C and Z with the respective poles of the battery, the conducting wire revolves round the pole N of the magnet.

If the current be descending, and N be the north pole of the magnet, the rotation will be direct.

These two rotations may be exhibited in one piece of apparatus, as represented in Fig. 96, where *m* represents the revolving small magnet,

Fig. 95.

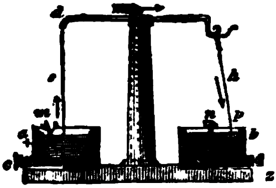


Fig. 96.

which is best made with a sewing needle; *f p* the revolving wire; *c* the positive pole of the battery; and *z* the negative pole. When the north poles of the magnets are both turned upwards, the rotations take place in the directions of the arrows, as shown in the figure. Reverse the direction of the electric current, and the rotations will be reversed.

Ampère's rotation of a current about the pole of a magnet.

On the two poles N and S of a permanent horseshoe magnet are placed two cells of copper, (*a c c e n* on N, and *e z z a n* on S;) *b d*, *b d*, are copper wires attached to cylinders of amalgamated zinc, which dip into the diluted sulphuric acid, filling the cells; these zinc cylinders turn on pivots at *s s;* the zinc cylinders revolve round the respective poles of the magnet in contrary directions; that is, in the directions indicated by the arrows.

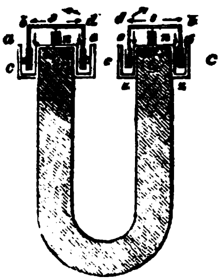


Fig. 97.

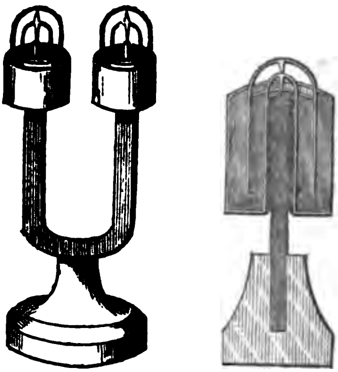


Fig. 98.

Fig. 98 represents a slight modification of the foregoing; here the copper cell turns upon a pivot, as well as the zinc cylinder; and for an obvious reason they revolve in contrary directions.

ELECTRO-DYNAMIC INDUCTION.

12. Faraday was the first philosopher who discovered the laws of electro-dynamic induction. He showed that an electric current, or a magnet, is able by induction to develop at a distance electric currents in a conducting wire; in the same way as common electricity electrizes an insulated conductor by induction.

Exp. 1. To show the induction of a current by magnetism. Take the coil, represented in Fig. 81, and place its extremities C and Z in connection with the respective binding screws of a galvanometer; suddenly insert a strong cylindrical magnet within the coil, and the needle will be instantly deflected, but it will almost immediately return to its original position; suddenly withdraw the magnet, and the needle will be deflected in the opposite direction.

Thus it appears that the induction of the current acts only at the instants of application and withdrawal of the magnet.

This explains the principle on which Clark's magneto-electric machine acts.

Exp. 2. Attach small copper cylinders near to the respective extremities of the wire C and Z; and place a bundle of soft iron rods (insulated from each other by a coating of shell lac) into the coil; connect the wires C and Z with the poles of the battery; hold the copper cylinders in the hands, and suddenly withdraw one of the wires from the pole of the battery, and a pretty powerful electric shock will be felt, and at the same time a spark will be given off from the point of the wire; at the moment of restoring the contact, another shock will be felt.

The current produced in these experiments is called a *primary current;* a *secondary current* is produced in the following manner:—

Over the coil of wire described in the foregoing experiments, let an exactly similar coil be formed upon it; let Fig. 99 represent this double coil, where *a* and *b* are the ends of the first or *primary* coil, *c* and *d* the ends of the second or *secondary* coil. Connect the ends *a* and *b* with the poles of a battery, and the ends *c* and *d* with a galvanometer; then the needle will be instantly deflected, showing that a secondary current had been induced in the second coil by the primary current in the first coil; suddenly take away one of the wires from the cup of the galvanometer, and the needle will be deflected in the opposite direction. The induced currents only exist for an instant, viz., at the instant of making or of breaking the contact.

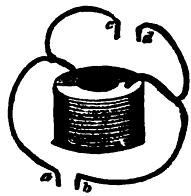


Fig. 99.

MAGNETO-ELECTRIC MACHINES.

13. One of the most simple machines of this kind is represented in Fig. 100. J J is a sectional representation of a double induction spiral; *r r* the wooden hollow roller on which the primary coil of *stout* copper wire *a a* is wrapped; *b b* the secondary coil of fine wire surrounding the first coil; *m* the bundle of iron wires placed in the hollow axis of the coils, and projecting with its lower pole a little beyond the wooden cylinder; one end *z* of the wire of the primary coil is connected with one pole of a constant battery, and the other end *y h f x* of the wire of the primary coil with the other pole of the battery; that portion of the conductor *p h e f*, between the two binding screws *y* and *x*, acts as the contact breaker. This *contact breaker* is constructed as follows: it

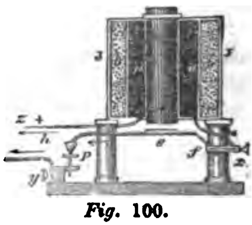


Fig. 100.

is soldered at *f* to a flexible plate screwed to the rod proceeding from the binding screw *x*; *e* is a plate of soft iron, soldered to the conducting wire, exactly under the electro-magnetic rods *m*; at *h*, the conducting wire is bent downwards, and terminates with a hammer, having a platinum point, which rests upon a copper plate or anvil *p*. When the hammer *h* is in contact with the anvil *p*, the electrical current is complete, and the soft iron wires *m* become powerfully magnetized by the primary current; the magnet then attracts the plate *e*, and breaks the contact, the rods instantly lose their magnetism, and then the hammer *h* falls upon the anvil *m*, and thereby again restores the electrical current; and so on. This process goes on with great rapidity, so long as the connection of the wires *z* and *y* with the poles of the battery is maintained.

Vivid sparks are emitted between the hammer and the anvil, every time the connection is broken or made.

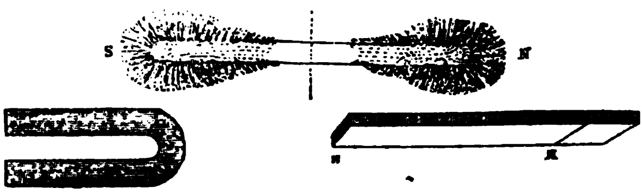
Substances, to be subject to the action of the electric current, must be interposed between the binding screws *x* and *y*; thus the thermal, chemical, magnetizing, and physiological effects may be observed at the instant the contact of the hammer with the anvil is broken or destroyed.

But the secondary current is that which should be used for producing the shocks or physiological effects. For this purpose, the extremities of the wire forming the secondary coil *b b* are soldered to small copper cylinders, and these are held in the hands of the person wishing to receive the shocks, one cylinder in each hand. A rapid succession of shocks is felt, for the effect takes place at every time the contact of the hammer with the anvil is broken or renewed.

This machine has been constructed in various forms; sometimes Richie's rotating magnet is used for breaking and renewing the connection of the conducting wire of the primary coil with the poles of the battery.

Faraday's Magneto-electric Machine.

14. The first machine of this kind was constructed by Faraday, as shown in Fig. 101. It is thus described by Brand in his Manual of Chemistry.



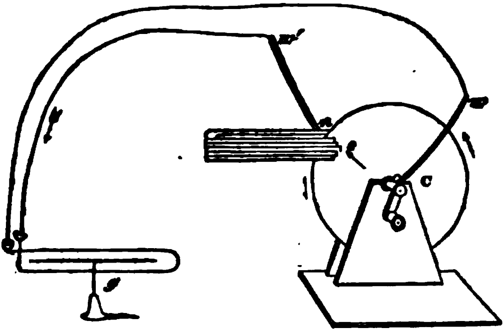


Fig. 101.

C is a copper plate, so mounted as to admit of revolving on its axis; *n s* are the poles of a powerful horseshoe magnet, so placed as to admit of the revolution of the plate between them; *w w'* are conducting wires, one of which is retained in metallic contact with the axis, and the other with the rim of the plate, at the point between the poles *n s*. These wires are connected with the galvanometer *g*. When the copper plate is made to revolve from right to left, a current of electricity is produced in the direction of the arrows, and deflects the galvanometer accordingly.

Clark's Magneto-electric Machine.

15. Pixii first made a machine of this kind, which was successively improved by Saxton and Clark. The arrangement adopted by Clark is thus described by M. Becquérel in his treatise on Electricity.

A (Fig. 102) represents a series of six magnetized bars of steel, bent into a horseshoe form, arranged vertically, and supported by four screws fixed to the board B, two of which are seen at M N, (Fig. 103.) A thick bar of brass C is pierced in its centre by an opening, into which passes a bolt with a nut for the purpose of securing the magnet against the board B. By this arrangement the magnet may be easily removed without disturbing the rest of the apparatus. D represents the armature of a double cylinder of soft iron G F, which is fixed to a brass screw placed between the poles of the battery A. This piece is set in motion in the manner indicated in Fig. 103, by means of the wheel E of an axis of rotation and an endless cord. On each cylinder is rolled a helix of fine copper wire, coated with silk, and about 800 yards in length. One of the ends of each helix is soldered to the armature;

perpendicular to the surface of which, at D, is a brass rod supporting two break-pieces H. K represents a hollow brass cylinder, to which is soldered one of the free ends of the helices, and which is separated from

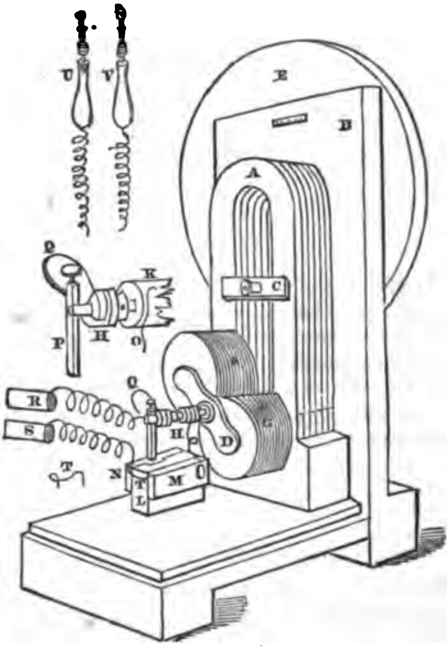


Fig. 102.

the rod by means of a piece of hard wood resting on it; the other end of the helices is in communication with the rod. O is an iron wire spring to exercise a pressure against the hollow cylinder K, with which it is in metallic contact, by means of a screw fixed in the brass plate M. P represents a square, vertical brass rod, fitted into the brass plate N. Q is a metal spring, exercising a feeble pressure on the break piece H: it is held in metallic contact by means of a binding screw. T is a copper wire for making communication between the brass plates M N. By means of this arrangement, these various parts D, H, Q, P, N, are in connection with one of the ends, and K and M with the two other ends. It is very evident that, as the spring Q presses gently on the break-piece H, the effects are regular. . . . . It is very necessary that the break-

piece be so arranged that the spring Q shall separate at the very time when the iron cylinders of the armature are leaving the poles of the magnet. With respect to the iron wire O, it always exercises a gentle

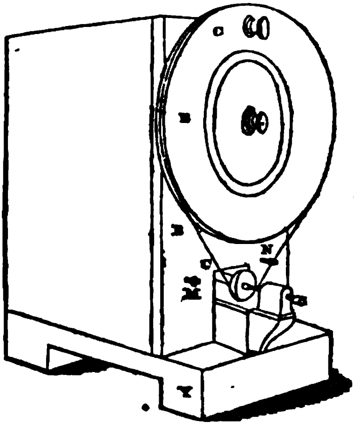


Fig. 103.

pressure against the hollow brass cylinder K. By means of these arrangements, a mercury bath, which is always inconvenient, is superseded. When the shock is to be given by this machine, the two copper conductors R S (Fig. 102) are taken into the hands, which are moistened with salt water, one of the conductors being in communication with the plate M, and the other with the plate N, in the manner shown in the figure; M and N are then united by the piece T. The shock received by this apparatus as soon as the wheel is turned is very violent. If we desire a current always in the same direction, one break-piece only is placed on. In this case, the circuit is interrupted when the current changes, that is, when each helix quits one branch of the magnet. . . . On placing the two connecting wires R S between M N, the shock is not so powerful. U and V (Fig. 102) are handles connected with the conducting wires, and furnished with pieces of sponge, which are employed in the application of electricity for medical purposes. These sponges are moistened with acid or saline solutions. By means of them a succession of the most powerful shocks may be applied where they are needed. . . . To decompose water, Mr. Clark uses the apparatus (Fig. 104) arranged in the following manner: A is an earthen vessel with a brass lid, having a base of hard wood, through which pass two copper wires soldered to platinum wires, and which are connected with

M N. Two tubes A are filled with water, and then placed over the platinum wires, where they are supported by a cork. The two plates of platinum C and D, which are connected by copper wires with M and N,

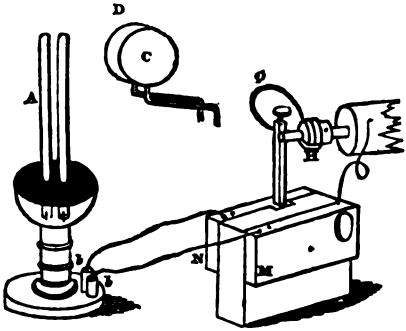


Fig. 104.

are for showing the effects of electro-chemical decompositions. For this purpose, a piece of litmus or turmeric paper, previously moistened with a neutral salt, is placed between the disks. In the place of the two pre-

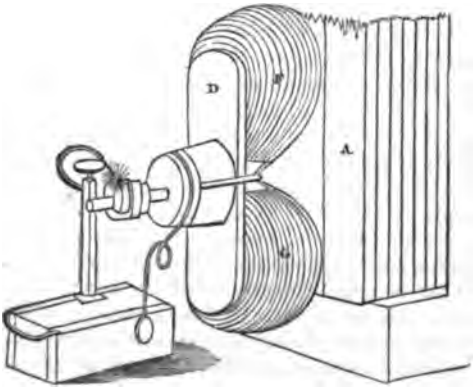


Fig. 105.

ceding helices and their accessories, which he calls the *intensity armature*, because the current obtained is from electricity of high tension, Mr. Clark employs a quantity armature, formed of less powerful cylinders, and with a copper wire, covered with silk, only 45 yards long, the diam-

eter of which is greater. Fig. 105 represents the apparatus furnished with this new armature. A is the horseshoe magnet, D the armature, F and G the two helices. Attention must be paid that the spring quits the break-piece at the moment when the piece is vertical, for then it is that it is in a neutral position relative to the poles of the magnet. To fuse iron wire with bright scintillations, one end of the wire is connected with the end P, and the other end is gently pressed on the rotating armature D. If we wish to obtain sparks of different colors by the employment of different metals, the break-piece is taken away, and the piece of copper B (Fig. 106) is substituted. In its open part is introduced a piece of any metallic wire C, gold, for example; the extremity of the spring G is also of gold. On making the apparatus rotate, purple-colored sparks are obtained.

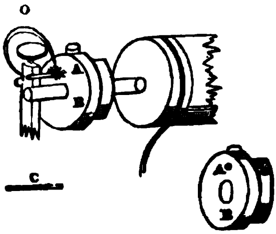


Fig. 106.

THERMO-ELECTRICITY.

16. The electricity which is developed by heat is called thermo-electricity. When two different metal rods, such as copper and platinum, or antimony and bismuth, are soldered together, and heated at the part of junction, electricity is generated.

Exp. 1. Twist the end of a copper wire round one end of a platinum wire; place the other extremities in connection with the binding screws of a galvanometer; heat the twisted extremities with the flame of a spirit lamp; the needle of the galvanometer will be instantly deflected.

Exp. 2. Fix two copper wires into the binding screws of a galvanometer; heat the free end of one wire with the flame of a spirit lamp; bring the free end of the other wire into contact with this heated wire; the needle will be instantly deflected, thereby showing the existence of an electric current. It is desirable that the end of the wire which is to be heated should terminate with a small plate.

Exp. 3. The simple apparatus represented in Fig. 107 exhibits the effects of thermo-electricity in a very striking manner. *a b c d e* is a strip of copper, bent into the form shown in the figure, and riveted at *e*. A

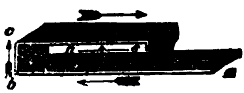


Fig. 107.

small magnetic needle *n s* is suspended between the plates. Heat the free end *a* of the copper frame with the flame of a spirit lamp, and the needle will be instantly deflected.

Thermo-electric Batteries.

17. These batteries are formed by soldering together a series of pairs of metal bars, as shown in Fig. 108, where the dark lines represent the bars of the same kind of metal, and the faint lines those of the other kind of metal. Heat is applied at the junctions *a a a*, while the junctions *b b b* are kept cool. The extreme ends *a b* form the poles of the

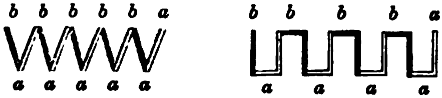


Fig. 108.

battery, which may be connected with binding screws, &c. Bismuth and antimony are the two metals most commonly used in constructing these batteries, when the heat employed is moderate; but if the heat to which the battery is to be exposed is great, platinum and iron should be used.

A thermo-electric battery is sometimes used as a thermometer. Fig. 109 represents an apparatus of this kind. *a* the tin or brass box which contains the thermo-battery S, composed of bismuth and antimony bars, arranged according to the principle explained in connection with Fig. 108; *m* and *p* the binding screws connected with the poles of the battery; wires pass from these binding screws to the galvanometer; *b* and *c* are the two lids of the box. When heat, in any form, is applied at S, the deflection of the needle indicates the degree of temperature of that heat. This instrument is much used for detecting *very minute* differences of temperature. A good instrument will readily detect, by the deflection of the needle, a difference of temperature of a hundredth part of a degree.

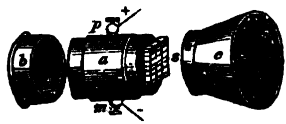


Fig. 109.

ACTION OF ELECTRO-MAGNETS UPON DIFFERENT BODIES.

18. All bodies which are capable of being magnetized are called *magnetic* bodies; but Faraday has recently shown that

magnetism exerts on all bodies, more or less, a certain peculiar influence, very different from the magnetic; those bodies are called *dia-magnetic.* Thus the flame of a candle undergoes a peculiar change when placed between the poles of a powerful magnet; and light, when made to pass over the poles of a magnet, undergoes a change of polarity; and so on to various other dia-magnetic bodies.

THE ELECTRO-MAGNETIC TELEGRAPH.

19. By means of very simple expedients, the current of magnetism may be interrupted hundreds of times in a second, being fully reëstablished in the intervals. These effects are in no way modified by the *distance* of the place of interruption of the current from the magnet. Thus pulsations of the current may be produced by an operator in Boston, and the simultaneous pulsations of the magnetism may take place at New Orleans, provided only that the two places are *connected by a continuous series of conducting wires.*

Now, if the extremity of a lever which is attached to the vibrating armature carry a pencil which presses upon paper, when the lever is drawn towards the electro-magnet, and if at the same time the paper is moved under the pencil with a uniform motion, *a line will be traced upon the paper by the pencil,* the length of which will be proportionate to that of the interval during which the lever is held in contact with the stop. As the operator in Boston can regulate this interval at will, by controlling the flow of the electric current, making that current act for a short interval if he desire to make a short line upon the paper, for a long interval if he desire to make a long line, and for an instant if he desire to make merely a dot, it will be understood how he can at will mark a sheet of paper at New Orleans with any desired succession of lines of various lengths, or of dots, and how he may combine these in any way he may find suitable to his purpose.

MORSE'S TELEGRAPH.

20. This apparatus, which is applied on an extensive scale in America, and with some slight modifications in Germany, is constructed upon the principle just explained.

A general view of the instrument in its most usual form is given in the following figure.

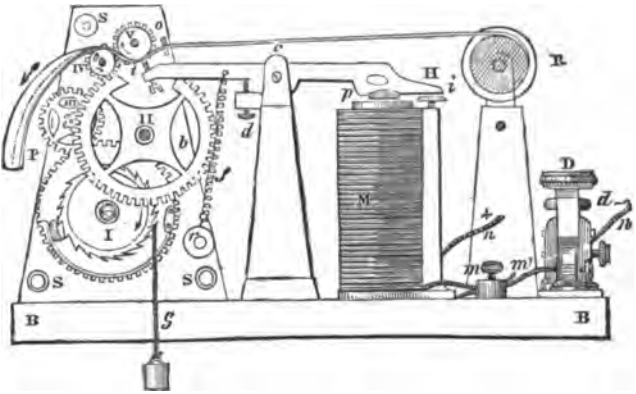


Fig. 110.

M is the electro-magnet; H is an armature working on the centre *c*; *i* is an adjusting screw, to limit the play of the armature and prevent its contact with the electro-magnet at *p*; *d* is another adjusting screw, to limit its play in the other direction; *t* a metallic style, which marks by pressure a band or ribbon of paper drawn from the roll R, and carried between the rollers *o* and *o'*; P the ribbon of paper discharged from the rollers *o o'* after being impressed by *t* with the telegraphic characters; I, *b*, &c., clockwork from which the rollers *o o'* receive their motion, by which motion the ribbon of paper is drawn from the roll R; *f* the spring which draws the arm H of the electro-magnet from the armature; S S the upright pieces supporting the clockwork; B B the base supporting the instrument; D the key commutator, by which the current transmitted along the line wire is alternately transmitted and suspended; *m n*, *m' n'*, wires by which the coil of the electro-magnet and the poles of the station battery are put in connection with the line wires.

The following are the telegraphic characters adopted by Professor Morse for the English language: —

A . —	J — . — .	S . . .
B — . . .	K — . —	T —
C . . .	L ——	U . . —
D — . .	M —	V . . . —
E .	N — .	W . ——
F . — .	O . .	X . — . .
G — — .	P	Y . . — . .
H	Q . . — .	Z . . . .
I . .	R . . .	& . . . .

Numerals.

1 · — — ·	6 · · · · · ·
2 · · — · ·	7 — — · · ·
3 · · · — ·	8 — · · · ·
4 · · · · —	9 — · · —
5 — — —	0 ——

BAIN'S ELECTRO-CHEMICAL TELEGRAPH.

21. The *chemical* properties of the electric current can be made to supply the means of transmitting signals between two distant stations. When a current of adequate intensity is made to pass through certain chemical compounds, it is found that these are *decomposed*, one of their constituents being carried away in the direction of the current, and the other in the contrary direction.

Of the forms of telegraph in which this principle is brought into play, the only one which has been practically applied on an extensive scale is that by Mr. Alexander Bain.

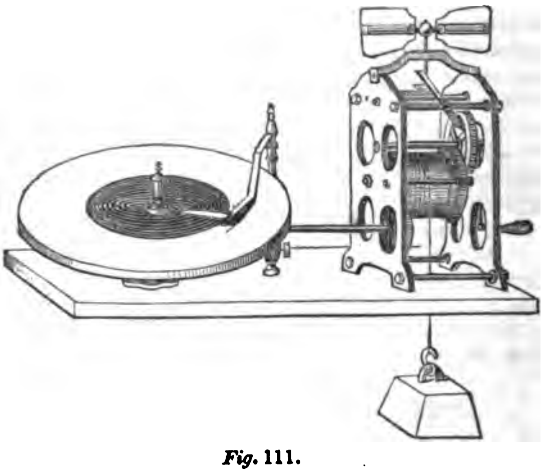


Fig. 111.

To understand this instrument, let us suppose a sheet of writing paper to be wet with a solution of prussiate of potash, to which a little nitric and hydro-chloric acid have been added. Let a metallic desk be pro-

vided corresponding in size with the sheet of paper, and let this desk be put in communication with a galvanic battery so as to form its negative pole. Let a piece of steel or copper wire, forming a pen, be put in connection with the same battery so as to form its positive pole. Let the sheet of moistened paper be now laid upon the metallic desk, and let the steel or copper point which forms the positive pole of the battery be brought into contact with it. The galvanic circle being thus completed, the current will be established, the solution with which the paper is wet will be decomposed at the point of contact, and a blue or brown spot will appear. If the pen be now moved upon the paper, the continuous succession of spots will form a blue or brown line; and the pen being moved in any manner upon the paper, characters may be thus written upon it, as it were, in blue or brown ink.

By means of wheelwork, the metallic desk is made to revolve round its centre in its own plane, while the style receives a slow motion directed from the centre of the disk towards its edge. In this way the style traces a spiral curve upon the paper, winding round it continually, and at the same time retiring constantly but slowly from its centre towards its edge. It will be evident, without further explanation, that characters may thus be produced on the prepared paper corresponding to those of the telegraphic alphabet already described in Morse's Telegraph.

HOUSE'S TELEGRAPH.

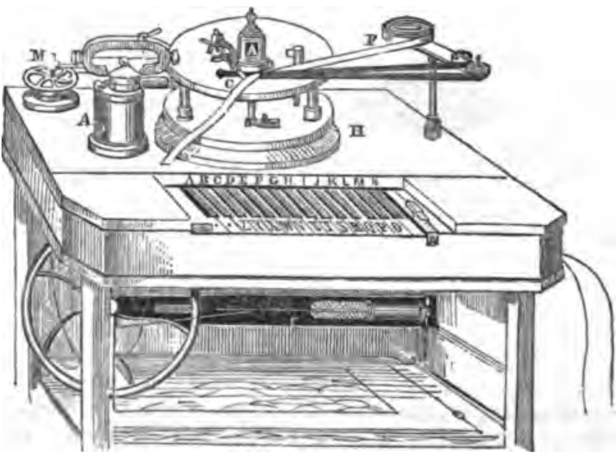


Fig. 112.

22. This apparatus, which is in extensive use in the United States, is a printing telegraph — that is, an instrument which prints in the *ordinary letters* the despatch at the station to which it is addressed, by means of a power worked at the station from which it is transmitted. It consists of two distinct parts — a commutating apparatus, to govern the transmission of the current, and a printing apparatus, upon which the current operates.

The transmission of the current is controlled by the keys of the finger board. The wheel that produces by its revolution the pulsations of the current is moved by the foot of the operator acting upon a treddle. The rotation of this wheel is arrested at the point corresponding to any desired letter, by putting down with the finger the key upon which that letter is engraved.

23. Mr. Bernstein, of Berlin, has invented a modification of the electric telegraph, which promises to extend the advantages of that machine in a remarkable manner. The peculiarity of the invention is, that by one wire two different messages can be sent in the same or in opposite directions at one time. Experiments were made in London with the new machine, and they are said to have fully established its powers.

TELEGRAPH LINES IN THE UNITED STATES.

24. Owing to the rapid progress and unrestricted freedom of enterprise in the United States, a great number of independent companies have been formed, by which the vast territory from the Atlantic Ocean to the Mississippi, and from the Gulf of Mexico to the frontiers of Canada, is overspread with a network of wires, upon which intelligence of every description, and personal and commercial correspondence, are flowing night and day, incessantly, from year to year, in a torrent of which the old continents offer no similar example.

The American lines are generally classified according to the telegraph instruments with which they work. These are those of Morse, House, and Bain; all of which transmit despatches by means of a single conducting wire, and all of which write or print the despatches they transmit — those of Morse and Bain in a telegraphic cipher, and that of House in the common Roman capitals.

Of these three systems, that of Morse is in the most general use — a circumstance which is partly explained by the fact that it was the earliest adopted, and had established its ground long before either of the competing systems. It must be admitted that, so far as public opinion and favor can be accepted as a test of practical excellence, the system of Morse has received not only a large majority of patronage in the United States, but also in the northern and eastern states of Europe. In 1854, the total extent of telegraphic wire then in operation in the United States

was above 40,000 miles; of which Morse's had 36,972 miles, House's 3850 miles, and Bain's 570 miles.

The most distant points connected by electric telegraph in North America are Quebec and New Orleans, which are 3000 miles apart; and two separate lines connect New York with New Orleans, — one running along the seaboard, the other by way of the Mississippi, — each about 2000 miles long. Messages have been transmitted from New York to New Orleans, and the answers received, in the space of three hours, though they had necessarily to be written several times in the course of transmission.

The electric telegraph is used by all classes of society as an ordinary method of transmitting intelligence.

Government despatches, and messages involving the life or death of any persons, are entitled to precedence; next come important press communications; but the latter, if not of extraordinary interest, await their regular turn.

Interruptions occur most frequently from the interference of atmospheric electricity; in summer, they are estimated to take place, on an average, twice a week. Other accidental causes of interruption occur irregularly, from the falling of the poles, the breaking of wires by falling trees, and, particularly in winter, from the accumulated weight of snow or ice.

The electric current is made to act through long distances by using local and branch circuits and relay magnets, in those systems where it would be otherwise too weak to operate effectually.

No adaptation of the system can be more interesting and useful than that which is made for the purpose of conveying signals of alarm and intelligence in the case of fire. This has been completely developed in Boston. The city is divided into seven districts, each provided with a powerful alarm bell. Every district contains several stations; there are altogether in the seven districts forty-two stations, all of which are connected with a chief central office, to which intelligence of fire is conveyed, and from which the alarm is given.

At each of the stations there is erected, in some conspicuous position, a cast-iron box containing the apparatus for conveying intelligence to the central office; and by striking the signal bell a certain number of times, the district and station from which the signal is made are indicated. An attendant is always on the watch at the central office; and when his attention is called to the signals by the striking of a large call bell, he immediately sets in motion his alarm apparatus, and, by depressing his telegraph key, causes all the alarm bells of the seven districts to toll as many times in quick succession as will indicate the district where the fire has occurred — the alarm being repeated, at short intervals, as long as may be necessary.

ASTRONOMY.

OBJECTS OF ASTRONOMY.—GENERAL VIEW OF THE HEAVENS.

1. ASTRONOMY is that science which treats of the heavenly bodies — the sun, the moon, and the stars.

THE STARS.

2. When we look at the heavens, on a clear night, they appear to us like a vast dome, or concave hemisphere, in which the stars shine like so many brilliant gems of light.

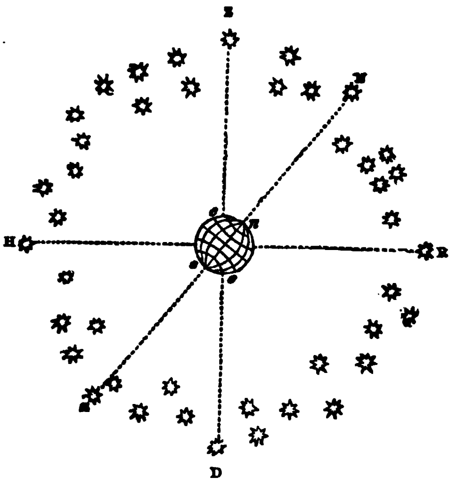


Fig. 1. The Stars.

The point directly over our heads is called the *zenith*, and the line where the sky and the earth appear to meet is called

the *horizon*. The *nadir* is that point in the heavens which is opposite to the zenith; that is, it lies directly below our feet.

Thus in Fig. 1, let *c n e s* represent the earth, and *c* the place of a person looking at the stars; then Z is his zenith, D his nadir, and H R his horizon; H Z R is the hemisphere, or half sphere, of stars which are visible to him, and H D R the opposite hemisphere, which would be visible to a spectator at *e* on the opposite side of the earth.

In the daytime we do not see the stars on account of the superior light of the sun; just in the same way as we should not see the flame of a candle, at the distance of a few hundred yards from us, when the sun is shining; but with a telescope the stars can be seen at any time of the day.

CARDINAL POINTS.

3. If you look towards the sun at noon, your face is directed to the south; your back is towards the north; the east is on your left hand; and the west is on your right. These four points in the horizon are called the *cardinal points*. Your shadow at noon is shorter than it is at any other time of the day, because the sun has then attained his greatest elevation above the horizon. The sun rises towards the east, and sets towards the west. At noon the sun is said to be on the *meridian;* and the time which elapses between his leaving the meridian and returning to it again is called a *solar day*.

DIURNAL MOTION OF THE HEAVENS.

4. If we look attentively at the stars, on a cloudless night, we shall see one star after another rising above our horizon in the east, and star after star *setting*, or sinking beneath our horizon in the west. A little farther observation will show us that the whole visible heavens appear to turn from east to west about a certain little star, considerably elevated, called the *polar star;* and that a complete revolution is made in the course of every day. Now, this *apparent* motion of the heavens, as we shall afterwards see, is really produced by the

revolution or turning of the earth from west to east, round a line or axis, which we may conceive to be drawn through the centre of the earth and the polar star. This is called the diurnal motion of the heavens, because it is performed in the course of a day.

In Fig. 1, N represents the north polar star, N S the line round which the heavens appear to turn, or the line round which the earth really turns.

MAGNITUDE OF THE STARS.

5. In a clear night about two thousand stars may be seen with the naked eye, but with a small telescope many millions may be observed. The stars appear to us of different sizes and degrees of brightness; the largest and brightest are said to be of the first magnitude; the next in order of the second magnitude; and so on to the sixth magnitude, which comprises those very small stars which are just visible to the naked eye. There are only eleven stars of the first magnitude in our hemisphere, and six in the southern, or opposite hemisphere. There are about fifty of the second magnitude, visible to us, and not less than one hundred and twenty of the third magnitude.

FIXED STARS AND PLANETS.

6. Nearly all the stars which we see are fixed; that is to say, they do not change their distances from one another, but always present the same outline of form. Some of the stars, however, do not always remain in the same place, but move among the *fixed stars:* these stars are called *planets.*

The fixed stars are also distinguished from the planets by having a more twinkling sort of light; and viewed through a telescope, the planets look like little luminous globes, while the stars simply appear like brilliant points of light without any appreciable size.

CONSTELLATIONS.

7. The ancient astronomers, for the convenience of reference, formed the fixed stars into constellations, or groups of stars, and represented them by animals, and other things, to which they imagined the outline of the stars, in each group, had some resemblance. The most striking of the constellations is that of the *Great Bear*, which is commonly known by the name of *Charles's Wain*, or wagon. Sailors call it the *dipper*.

The form of this constellation is shown in Fig. 2, where the four stars *a b c d* are supposed to represent the body of the dipper, and the remaining three the handle. The two stars *b a* are called *the pointers*; for if a line be drawn through them it will very nearly point to the polar star N.

Fig. 2. Constellation of the Great Bear.

If a line be drawn from the star *e*, leaving *v* a little to the left, it will pass through a very brilliant star A, called *Arcturus*, which is the principal star in the constellation of *Boö'tes*.

The names of the different constellations may be readily acquired by looking at a celestial globe, which is constructed to represent the aspect of the heavens. These constellations always present the same appearance; the hoary-headed man, tottering on his grave, as he takes, it may be, a last look at Charles's Wain, well remembers that it presented the same aspect when he first gazed upon it in the joyous days of his childhood.

SIGNS OF THE ZODIAC.—THE ECLIPTIC.

8. There is a remarkable class of constellations, extending round the heavens, like a band or belt, in which the planets always appear to move; this belt of stars contains twelve constellations, which are called *the signs of the zodiac.* The sun also appears to us to make a complete revolution in the heavens, in the course of a year, through the different constellations of the zodiac. This apparent path of the sun in the heavens is called *the ecliptic;* the constellations of the zodiac, therefore, mark out the ecliptic in the heavens. The term *zodiac* means *animal*, and this apparent path of the sun was, no doubt, so called on account of the names given to the various constellations composing it. The zodiac is divided into twelve signs, to correspond to the twelve months of the year. The following table gives the names of the signs of the zodiac, with the marks or symbols which are put for them.

Names of the Signs of the Zodiac.

Aries . .	*the Ram* . .	♈	Libra . .	*the Balance* . .	♎
Taurus .	*the Bull* . . .	♉	Scorpio .	*the Scorpion* .	♏
Gemini .	*the Twins* . .	♊	Sagittarius	*the Archer* . .	♐
Cancer . .	*the Crab* . .	♋	Capricornus	*the Goat* . .	♑
Leo . . .	*the Lion* . . .	♌	Aquarius .	*the Waterman* .	♒
Virgo . .	*the Virgin* . .	♍	Pisces . .	*the Fishes* . .	♓

GENERAL PRINCIPLES OF ASTRONOMY.

9. In the study of astronomy, it is above all things necessary that we should reason upon appearances, and that we should allow the first rude notions, derived from the senses, to be corrected by the judgment. As these remarks are essential to a right appreciation of our methods of exposition, it will be instructive to elucidate them by taking one or two familiar cases.

The cross at the top of St. Paul's cathedral *appears* to us not longer than a walking stick, whereas its length is *really* greater than the eleva-

tion of an ordinary house. Here, by taking into account the distance of the cross from us, we are able to assign a reason for its apparent smallness. In precisely the same way, the moon appears to us scarcely larger than a man's face; but when we consider that it is many thousands of miles from us, we should be prepared for adopting the fact that it is a world not much smaller than the earth on which we live. In like manner, we should be led to expect that the planets, which, owing to their still greater distances from us, appear like little balls of light, are in reality vast globes, many of which are considerably larger than our earth.

When we are moving in a railway carriage, we should from appearances believe, if our reason did not correct this belief, that the houses and trees were moving, and that we were sitting still. In like manner, we should be prepared to question the truth of the first impression of our senses, when we are led to imagine that the whole of the heavens turn round us in every twenty-four hours, and to ask ourselves, "Is it not more rational to suppose that this apparent motion is produced by the actual rotation of our earth itself?" The science of astronomy has established many principles which are at variance with the first rude notions derived from mere appearances: the following general principles deserve especial attention:—

Our earth has the form of a globe; it turns or spins round upon its axis every twenty-four hours, and thus gives rise to the apparent diurnal or daily motion of the heavens; it also moves round the sun, in the course of a year, which occasions the apparent motion of the sun in the ecliptic. The planets are worlds like our own; and they, together with our earth, revolve round the sun as the common centre of attraction, in different paths or orbits; they also derive their light and heat from it. The sun, with all the planetary bodies which move round it as a centre, is called the *solar system*. The fixed stars, which are at immense distances from us, are suns, with their respective systems of unseen worlds revolving round them, probably similar to the solar system.

SOLAR SYSTEM.

10. The solar system consists of the sun, in the centre, round which all the planetary bodies revolve.

The leading planets move round the sun from west to east, in nearly circular orbits or paths, lying nearly in the same plane, or flat surface, that is, in the plane of the ecliptic, and

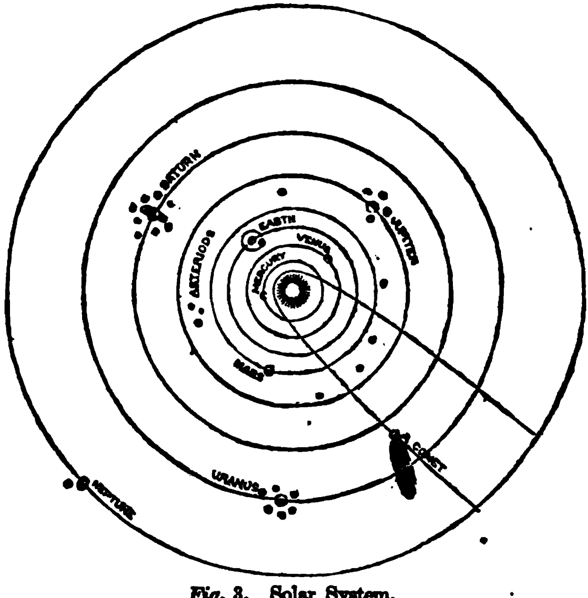


Fig. 3. Solar System.

rotate, or spin round on their axes, in the same direction. Some of the planets have moons or satellites revolving round them. The names of the planets, in the order of their distances from the sun, are MERCURY, VENUS, the EARTH, MARS, JUPITER, SATURN, URANUS, and NEPTUNE; together with ten small planets called ASTEROIDS, or little stars, which move in orbits lying between Mars and Jupiter. These are

called *primary planets;* there are also 20 moons or satellites, which are called *secondary planets*, because they revolve round their respective primaries in the same manner as the latter revolve round the sun. The moon is the satellite to the earth: it completes a revolution round the earth in the course of every lunar month. Jupiter has four satellites, Saturn eight, Uranus six, and Neptune one. Besides these, there is another order of bodies, which revolve round the sun called *comets;* they have blazing trails, and move in very eccentric orbits.

The solar system, as just described, was first taught by Pythagoras, an eminent Greek philosopher, who lived about 500 years before the time of Christ. But it was soon after disregarded, and various false systems were taught in its place, until about 300 years ago, when Copernicus revived the true system which had been discovered by the great Pythagoras.

The planets, with the other bodies composing the solar system, will be more fully described after we have considered the different motions, &c., of the earth and the moon.

THE EARTH AND ITS MOTION.

FORM AND SIZE OF THE EARTH.

11. The earth has the form of a *globe;* that is, it is like

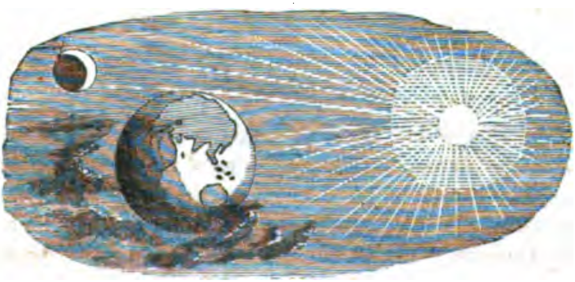


Fig. 4. The Earth in Space.

a ball or orange. This is proved by various facts; the following are given as being the most simple.

Navigators have sailed round the earth.

If a ship sail constantly in the same general direction, either eastward or westward, she will arrive at the same place from which she set out. Now, if the earth were an unbounded plain, or flat surface, the farther the ship sailed, the farther she would get from the point of departure. Magellan was the first mariner that sailed round the world, but Columbus was the first that made the attempt.

The earth, then, is a great globular mass of matter, without any fixed point of support; for navigators and travellers have crossed it in all directions, and no such point has ever been seen.

The hull of a vessel disappears as she leaves the shore.

When a vessel leaves the shore, at a little distance, a portion of the hull is observed to disappear; a little farther, the hull is lost to the sight; at a greater distance, the lower sails disappear; until at length, only the

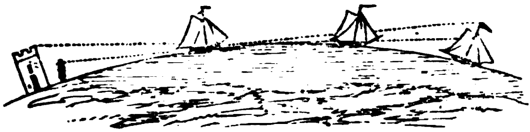


Fig. 5. Rotundity or Roundness of the Earth.

upper sails are seen in the *horizon*, or the line where the earth and sky appear to meet. But if we now ascend a high tower, we should get sight of the hull again. Now, if the earth were a flat surface, we should always see the hull at the same time that we see the topsails.

The earth always appears of a circular shape.

The *rotundity* or roundness is such, that a man six feet high, standing upon the sea shore, would see a little boat when its distance from him does not exceed three miles; but if he were elevated twenty-four feet, the boat would be seen at the distance of six miles; and if he were elevated fifty-four feet, the boat would be seen at the distance of twenty-seven miles; and so on: the distance at which the boat would be seen increasing with the elevation of the observer. In all these cases, the man's view is bounded by a *circular horizon*. Now, there is no body but a globe that will always appear of a circular shape when viewed at different distances.

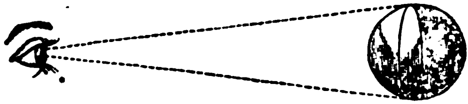


Fig. 6. A Globe always appears round.

At whatever distance I look at this little globe, it always appears to have a circular shape; and moreover, the farther it is removed from my eye, the greater is the extent of surface that I see. Mr. Green, when he goes up with his balloon, will see more of the earth's surface than we can, even though we should be on the top of Richmond Hill; and whatever may be his height above the earth's surface, he will always find that it presents a circular shape. When he has attained his greatest elevation, the largest hills and trees will appear to him just like the little irregularities which we see upon the surface of an orange.

Fig. 7. The Earth always appears round.

THE DIAMETER OF THE EARTH.

12. The *diameter*, or line passing through the centre of the earth, is about 8000 miles; and as the length of a line going round a circle is a little more than three times the diameter, it follows that the length of a line going round the earth, or the *circumference*, is about 25,000 miles. A railway train, moving with the speed of 50 miles per hour, would go round the earth in about 500 hours, or about three weeks, supposing there were no obstructions to the motion. This will give us some idea of the great size of the earth.

31 *

DIURNAL MOTION OF THE EARTH.

13. The earth has two motions — a *diurnal* or daily motion upon its axis, and an *annual* or yearly motion round the sun; that is, it turns round like a spinning top, and at the same time moves round the sun.

14. *Cause of Day and Night.* — The spinning motion, or revolution of the earth upon its axis, is the cause of day and night. When the sun shines upon our side of the earth, it is day with us, and when he shines on the opposite side, it is night with us.

If you hold a globe or orange before a candle, one half of the globe will be enlightened, and the other half will be in the shade; and if the globe be turned round, every portion will be successively brought within the light of the candle. The line *e f*, separating the light and shade, is called *the circle of illumination.* Let us suppose a little fly to be fixed on this globe; then, throughout one half of the revolution, the creature will be in the shade, and throughout the other half, the creature will be in the light. When the fly comes on the circle of illumination, it will then just begin to see the candle; and when it is passing out of the circle of illumination, on the other side, the candle will just be disappearing to it; but when it is in the middle of these two points, the candle will shine directly or perpendicularly over it, and here it will enjoy the greatest amount of light and heat from the candle. So it is with our earth; the sun enlightens one half of the earth at one time, the other half being in darkness. When a place just comes within the circle of *illumination*, the sun then begins to shine or rise to that place; and on the contrary, when the place is just going out of the circle of illumination, the sun will be disappearing or setting to that place; and midway between these two lines of illumination, the sun will shine directly over, or perpendicularly over the place, and then it will be noon to that place.

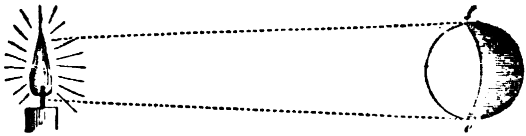


Fig. 8. Light and Shade.

Now, if the earth were standing still, one half of it would have perpetual day, and the other half would have perpetual night. But in order that the whole, or nearly the whole, of the earth may be habitable, it is ordained by our good and all-wise Creator, that the earth should turn round once every natural day, so that every portion might enjoy, in succession, the light and heat of the sun. This motion of the earth is called the diurnal or daily motion.

15. But how, it may be asked, do we think that the sun and stars move from east to west? Just in the same way as when we are in a railway carriage we believe, if our reason were not to correct the belief, that the nearest trees and houses have a motion *contrary* to that which we really have.

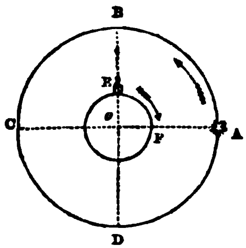


Fig. 9.

In order to illustrate this still further: let A represent an object capable of moving round the globe E F, which admits of turning on its axis *o*. First let the object A move round the globe in the direction of the arrow shown in the figure, while the globe itself remains at rest; the object at A will appear in the horizon to a spectator at E; but as the object moves, it will appear to the spectator to rise higher and higher above the horizon, until it arrives at B, when it will appear in the zenith, or directly over the head of the person. Next let the globe turn round on its axis *o*, in a direction *contrary* to that in which the object moved, as shown by the arrow in the figure, while the object A stands still; the apparent motion of the object, as seen by the spectator at E, will be exactly the same as before; thus, when the globe begins to revolve, the object A will appear to the spectator E to be in the horizon; but as the globe turns round, the object A will appear to rise higher and higher above the horizon, until the spectator has turned round to F, when the object will appear in his zenith, or directly over his head. Now, if the globe turned round on its axis without any jarring motion, or without any jolting or shaking, as the earth really does, so that our spectator might be altogether insensible of his own motion, then it is plain that he would at first believe that the object had moved from A to B, that is, from his horizon to his zenith, in the place of having himself moved round with the globe from E to F. Thus the *apparent* motion of the heavens, from east to west, would be produced by the *actual* rotation of the earth on its axis from west to east.

It would be opposed to the simplicity which we every where observe in the works of God, as well as at variance with the

known laws of mechanics, to suppose that the sun, with many thousands of worlds, most of which are vastly larger than our own, should move round our globe once in every day, when the same end could be served by our earth simply turning on its axis.*

LINES UPON THE GLOBE.

16. The earth, then, makes a complete revolution every day; the line about which it turns is called the *axis of the earth;* and the points where this imaginary axis pierces the earth's surface are called the poles; there are, therefore, two poles, the one being called the *north pole,* the other the *south pole.* If a line be drawn round the earth, every where at the same distance from the two poles, it will form the *equator.*

If you spin a globe upon its axis, you will find that the line which we call the equator has the quickest motion, and that the poles are the only

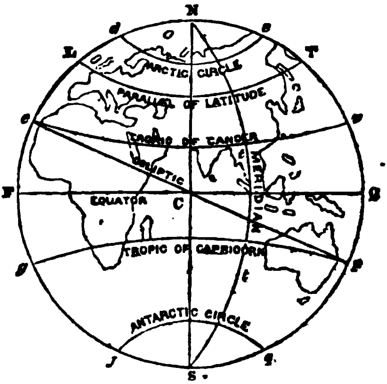


Fig. 10. The Globe.

points on the surface of the globe which have no motion. In this figure, N S represents the axis of the earth, N the north pole, S the south pole, E Q the equator.

* The rotation of the earth has recently been proved by an experiment with a long pendulum.

The equator, therefore, divides the earth into two equal parts; the portion E N Q is called the *northern hemisphere*, or half sphere; and the portion E Q S is called the *southern hemisphere*.*

Circles upon the globe are divided into 360 equal parts, and each part is called a degree. A semicircle, or half circle, will contain 180 degrees, (180°.) A quadrant, or quarter circle, will contain 90 degrees, (90°.) The distance of the equator from either of the poles will, therefore, contain 90°.

LATITUDE AND LONGITUDE.

17. A line drawn between the north and south poles is called a *meridian*, because, when any meridian is opposite to the sun, it is *midday*, or noon, to all places on that line. These circles will all, evidently, lie due north and south. Meridian lines are also called lines of longitude. The meridian passing through Greenwich is called the *first meridian*, or the one to which the position of all the others is referred.

18. The *longitude* of a place is its distance, in degrees, east or west, from the first meridian. Thus America has west longitude, whereas Asia and Africa have east longitude.

19. The *latitude* of a place is its distance from the equator. All places in the northern hemisphere have *north latitude;* and on the contrary, all places in the southern hemisphere have *south latitude*. Thus a place midway between the equator and north pole will have 45° north latitude; whereas a place midway between the equator and the south pole will have 45° south latitude. London, being 51½° from the equator, has 51½° north latitude.

20. Lines drawn round the earth parallel to, or even with, the equator, are called *parallels of latitude*. These lines are

* In giving these lessons, it is desirable that the teacher should be provided with a small white globe, having a rod passing through it to represent the axis of the earth, and having also all the essential lines upon the terrestrial globe, painted in strong black lines.

called *small circles*, because they are less than the *great circles*, or circles which divide the globe into two equal parts, like the equator. The use of parallels of latitude is to point out places that have the same latitude or distance from the equator. The latitude of a place will obviously be measured upon the meridian passing through the place.

21. In order to fix the exact position of a place, we must have its distances from *two* known lines. Thus my position in this room will be known when I tell you that I am twelve feet from the wall in front of me, and ten feet from the wall to the right of me. So it is with respect to the earth; when we know the distance of a place, north or south, from the equator, and at the same time its distance, east or west, from the first meridian, the position of that place becomes known. A meridian, drawn through a place, will cut the equator in a certain point, the distance of which from the first meridian, measured in degrees on the equator, will give the longitude of the place; and the distance of the place from the equator, measured in degrees upon the meridian, will give the latitude. Thus, if the meridian passing through the place lies 23° to the east of the first meridian, then the place will have 23° east longitude; and if the place be 40° north from the equator, the latitude will be 40° north.

22. Because the earth turns once on its axis from west to east, or describes 360 degrees in the course of twenty-four hours, it follows that the twenty-fourth part of 360°, or 15°, will be turned round every hour. A place, therefore, having 15° east longitude, will have noon one hour before us; and a place having 15° west longitude will have noon one hour after us. In general, we must allow an hour as the difference of time between any two places for every 15° difference of longitude. Thus Alexandria has 30° east longitude; consequently as many times as 15° can be taken out of 30°, so many hours will the people of this place have noon before us in London; that is, their noon will take place two hours before our noon.

23. By this means, seamen are enabled to find their longitude: suppose, for example, that the pointer of the clock which they take with them, keeping Greenwich time, should be at nine o'clock in the morning, when it is noon to the place of observation; then the difference of time being three hours, the difference of longitude will be three times 15°, or 45°; but as the place of observation has noon before us, it will consequently have 45° east longitude.

24. As the length of the parallels of latitude become shorter and shorter as they approach the pole, it follows that

a degree of longitude, estimated on any parallel of latitude, is shorter than a degree on the equator. This principle is observed in the construction of maps.

THE TROPICS AND ECLIPTIC.

25. If the sun were always shining perpendicularly over the equator, as in Fig. 11, the length of the day and night would always be equal all over the globe. The sun has this position at the commencement of our spring and autumn, that is, on the 21st of March and on the 22d of September.

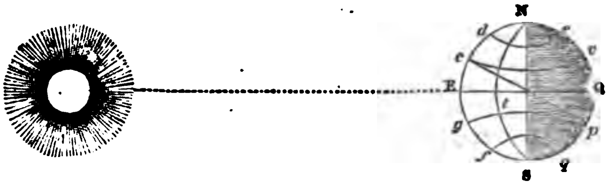


Fig. 11. The Sun in Spring and Autumn.

Owing to causes which will afterwards be explained, we find that during our midsummer day, the sun shines perpendicularly over a line *c v*, going round the earth 23½° on the northern side of the equator. (See Figs. 11, 12.) This line is called *the tropic of Cancer*, because the sun appears to us, at this time, amongst a certain group of stars

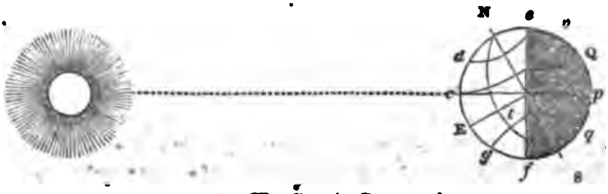


Fig. 12. The Sun in Summer.

called the constellation of Cancer, or the Crab. Now, as the sun enlightens one half of the globe at one time, it follows that his light must extend 23½° over the north pole, that is, to the point *e* in the figure, and a line *e d*, drawn round the earth parallel to, or even with, the equator, is called the *arctic circle*.

In like manner, during our midwinter day, (see Fig. 13,) the sun shines perpendicularly over a line *g p*, 23½° on the south side of the

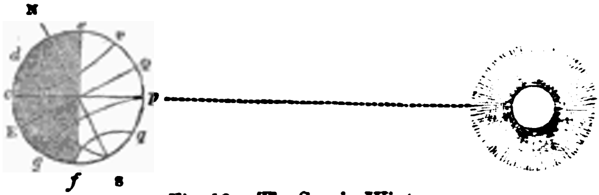


Fig. 13. The Sun in Winter.

equator; this line is called the *tropic of Capricorn*, because the sun appears to us, at this time, amongst a group of stars called the constellation of Capricorn, or the Goat; and the line *f q* in the figure, drawn round the earth at the distance of 23½° from the south pole, is called the *antarctic circle.*

If a line *c p* be now drawn round the earth between the tropics of Cancer and Capricorn, it will form the ecliptic or apparent path of the sun throughout our year. The ecliptic is, therefore, inclined to the equator at an angle of 23½°.

THE ZONES ON THE EARTH.

26. To mark out the climates upon the earth, its surface is divided into five zones or belts. The portion lying between the tropics of Cancer and Capricorn is called the *torrid zone*, or hot zone; for here the sun, shining almost perpendicularly upon the earth, will, in general, cause this portion to be very warm. The portion in the northern hemisphere lying between the tropic of Cancer and the arctic circle is called the *north temperate zone;* and the corresponding portion in the southern hemisphere, lying between the tropic of Capricorn and the antarctic circle, the *south temperate zone.* The surface within the arctic circle is called the *north frigid zone*, and that within the antarctic circle, the *south frigid zone;* because, from the slanting direction with which the sun's rays meet the surface of the earth at these regions, they are found to be, in general, very cold.

27. It is obvious that the only places on the earth to which the sun can be vertical are those lying within the torrid zone; and that to all such places there can be but little variation in the length of the days. Whereas within the frigid zones the sun will shine for a certain series of days without setting, and for a corresponding number of days he will not appear above the horizon.

28. The elevation of the polar star is equal to the latitude of the place.

To understand this, let us suppose that we are at the equator; then the polar star will be in our horizon, being 90° from our *zenith*, or the point over our heads. Now suppose we travel 1° on a meridian line, or directly towards the north pole, then the polar star will appear elevated 1° above our horizon; by travelling 2°, the polar star will appear elevated 2°; half way between the equator and the pole, our distance from the equator will be 45°, and then the polar star will appear to us elevated 45°, and so on. Thus it is that the elevation of the polar star gives us the latitude of the place. By this means navigators sailing on an expanse of ocean can find the latitude of the place where they are.

MEASUREMENT OF THE EARTH.

29. The same course of reasoning will show how *a degree on the earth's surface* is measured. At London, the elevation of the polar star is about 51½°; now if we travel due north until we find its elevation to be 52½°, we shall have travelled over 1°, or the 360th part of the earth's circumference; and if this distance be accurately measured, it will be found to be about 69¼ miles, which is consequently the length of a degree. The whole circumference of the earth will therefore be about 360 times 69¼ miles, or, in round numbers, 25,000 miles.

It must, however, be observed, that the earth is not an *exact* sphere, for it has been found that the length of a degree measured towards the poles is greater than it is at the equator; thereby showing that the earth is a little flattened at the poles, so that the diameter passing through the equator is about 26 miles greater than the diameter passing through the poles.

ANNUAL MOTION OF THE EARTH.—CAUSE OF THE SEASONS.

30. Besides the spinning motion of the earth upon its axis, we have said that it moves round the sun in the course of a

year, in a path, or *orbit*, which is nearly circular. This annual motion, combined with the unchanging direction, or *parallelism*, of the earth's axis, is the cause of the seasons.

Let the small globe be carried round a candle (covered with a glass shade about the same size as the globe) at the same time that it is kept spinning upon its axis; then we shall have a tolerably correct exhibition of the twofold motion of the earth, viz., its *diurnal* or daily motion on its axis, and its *annual* motion round the sun. The path in which the globe is moved will represent the *orbit* of the earth, and a level or even surface going through this path will represent the *plane* of the earth's orbit. Again, let our little globe be carried round the candle, with its axis perpendicular or upright to the plane of the orbit; then it will be seen that the circle on the globe separating the light and shade passes through the poles throughout the whole revolution; this position of the axis, therefore, will not account for the changes of the seasons.

Let the globe be now carried round the candle with the axis constantly inclined to the plane, or surface of the table, at the same angle; then, in every position of the globe, it will be seen that the axis always lies in the same direction, or that it is always parallel to itself.

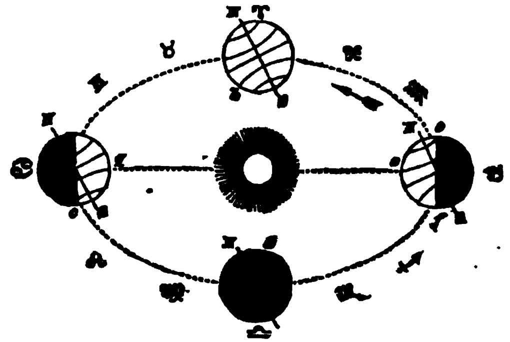


Fig. 14. Cause of the Seasons.

Let the globe have the position *e* in the figure, where the axis is inclined towards the sun, so that a rod extended from the candle, representing the sun, shall be perpendicular to the tropic of Cancer, at *e*; then, as the light will extend over 90° every way from *e*, the circle *e f* which separates the light and shade will pass 23½° over and beyond the north pole; and therefore, during the revolution of the globe on its axis,

the whole of the north frigid zone will be enlightened, and on the contrary, the whole of the south frigid zone will be in darkness. In order to illustrate this, suppose a little fly were placed upon the arctic circle; then throughout a whole revolution the creature will not have gone without the light of the candle; and on the contrary, let the creature be placed upon the antarctic circle; then, throughout a whole revolution it will not have come within the light at all. It will also be seen that all places in the northern hemisphere will be longer in the circle of light than in the circle of darkness; and on the contrary, all places in the southern hemisphere will be longer in the circle of darkness than in the circle of light; that is, in the former hemisphere, the day, as in our summer, will exceed twelve hours; whilst in the latter hemisphere, the day will be less than twelve hours. Whereas, exactly on the equator, the days will not alter in their length. This position of the globe corresponds to our midsummer, or 21st of June.

Constantly keeping the axis pointing in the same direction, let the globe be brought to the position *b* of the figure, where the axis neither inclines to the sun nor from the sun; now the light will fall perpendicularly on the equator; the circle separating the light and shade will pass through the poles, and therefore the days and nights will be equal all over the globe. This position corresponds to our *autumnal equinox*, the 22d of September, or to that time in autumn when the length of the night equals the length of the day. Still keeping the axis pointing in the same direction, let the globe be now brought to the position *q*, where the north pole inclines away from the sun. Here the *reverse* of what was observed in the first position *c* will now take place. The sun will shine perpendicularly over the tropic of Capricorn, and the southern hemisphere will enjoy more of the sun's light and heat than the northern. This position corresponds to our midwinter, the 21st of December, and then our days will be at their shortest.

Let the globe now be brought to the position *d* of the figure; then, here again, the axis neither inclining to the sun nor from the sun, the days and nights will be equal, as at the autumnal equinox. This position corresponds to our *vernal* or *spring equinox*, the 20th of March.

When the globe is brought to the position *c*, it has made a complete revolution in its orbit, and the period corresponds to our natural year, or 365 days, 5 hours, 48 minutes, and 51 seconds. Particular attention should be given to the circumstance that the axis of the globe, throughout the whole revolution, has *maintained its parallelism*.

31. While the earth thus performs a revolution in its orbit, the sun will *appear* to us to make a complete revolution in the heavens, through the different constellations in the *zodiac* or belt of stars. Thus, in our midsummer, the sun will be referred to the sign ♋, or constellation of

Cancer; in our autumnal equinox, to the sign of Libra, or ♎; in our midwinter, to the sign of Capricornus, or ♑; and in our vernal equinox, to the sign of Aries, or ♈.

32. Thus the changes of the seasons, as well as the apparent annual motion of the sun, are perfectly explained by supposing the earth to move round the sun. But why, it may be asked, do we, in opposition to the first impression of our senses, believe that the earth moves, instead of the sun? Just for the same reason that we infer that the *apparent* diurnal revolution of the sun round the earth is produced by the actual rotation of the earth on its axis in every twenty-four hours.

33. The distance of the earth from the sun is about ninety-five millions of miles. In order to form some conception of this immense distance, let us suppose a body to move from the earth to the sun with the speed of one of our railway carriages, (50 miles per hour;) then it would take about 220 years to arrive at the sun.

THE MOON.

34. The diameter of the moon is about 2000 miles, or about one fourth the diameter of the earth; she performs a revolution round the earth in 27 days, 7 hours, 43 minutes, in an orbit whose radius is about 240,000 miles, or about 60 times the earth's radius. The moon always presents the same face to us; hence it follows that she must turn round on her axis in the same time that she revolves round the earth.

MOUNTAINS AND CAVITIES ON THE MOON.

35. When the moon is viewed through a telescope, various spots, of different degrees of brightness and depth of shade, are observed on her surface. The darkest portions are caused by deep cavities and valleys; those of a lighter shade by the shadows of high mountains; and the brightest spots are the illuminated tops of the mountains, which look like the craters of volcanoes.

The heights of many of the mountains on the moon have been calculated from the lengths of the shadows which they cast. The loftiest of them are about two miles high. The moon has no clouds, nor have any decided indications of an atmosphere been observed. It therefore seems improbable that living beings, such as we are, can exist there.

The Earl of Rosse, who has recently completed another telescope, the largest ever made, alluded, at a late meeting in London, to its effects. He said that, with respect to the moon, every object on its surface of 100 feet in height was now distinctly to be seen; and he had no doubt, under very favorable circumstances, it would be so with objects 60 feet in height. On its surface were craters of extinct volcanoes, rocks, and masses of stones, almost innumerable. There were no signs of habitations such as ours: no vestiges of architecture remain to show that the moon is or ever was inhabited by a race of mortals similar to ourselves. It presented no appearance which could lead to the supposition that it contained any thing like green fields and the lovely verdure of this beautiful world of ours. There was no water visible — not a sea or a river: all seemed desolate.

PERIODICAL AND SYNODICAL MONTH.

36. Like the sun and planets, the moon, in consequence of her revolution round the earth, has an apparent motion from west to east among the stars of the zodiac. Her motion among the stars is so rapid that it may be readily perceived by a few hours' observation on any moonlight night. As already stated, she makes a complete revolution in the heavens in 27 days, 7 hours, 43 minutes; that is to say, she takes this time in passing from a star to returning to the same star again: this is called her *periodical month;* but the time from new moon to new moon again is rather longer than this, in consequence of the motion of the earth in its orbit. The time between every new moon is 29 days, 12 hours, 44 minutes: this is called the *synodical month.*

Let S (Fig. 15) represent the sun; E the earth; A B a part of its orbit; M C the orbit of the moon round the earth; M her position at new moon, which is in a line drawn from the earth to the sun. Now, if the earth had no motion, the moon would move round in her orbit and return to the position M in a periodic month; but while the moon is describing a revolution, the earth will have moved over about the twelfth part of its orbit, suppose from E to *e*. The moon will then be at *n*, where *e n* is drawn parallel to E M, and she must therefore move over an additional portion *n m* of her orbit before she comes again in the line *e* S joining the earth and the sun. This additional portion, being about the twelfth part of her whole orbit, occasions the time of the synodical revolution to

exceed the periodical by rather more than two days. This is well illustrated by the relative motions of the hour and minute hands of a watch:

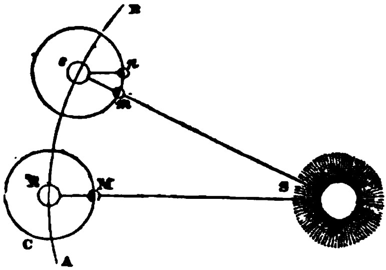


Fig. 15. Periodical and Synodical Month.

at 12 o'clock the hands are together, but before they can come together again the minute hand must move over a whole revolution and rather more than the twelfth part of another one.

THE MOON'S PHASES.

37. The sun always enlightens one half of the moon; but as her enlightened hemisphere is always directed towards the sun, she presents different phases of illumination to us as she moves in her orbit. Sometimes we see the whole of her enlightened disk, sometimes only a small portion of it, and at other times none at all.

Let E represent the earth; (see Fig. 16;) S the sun; and *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h* the moon in different parts of her orbit, having her enlightened hemisphere always turned towards the sun. The little circles outside of the line representing the moon's orbit show the moon's faces at the respective positions, as seen by an observer on the earth.

When the moon is at *a*, in a line with the earth and the sun, the dark face of the moon is turned towards the earth; the moon is then at her *change*, or she is called *new moon*. She is also at this time in *conjunction* with the sun.

At *b* a small portion of her enlightened hemisphere is turned towards the earth, and she then appears *horned*.

At *c* one half of her enlightened hemisphere is turned towards the

earth, and she then appears as *half moon*. This takes place at the end of her first quarter, or at her quadratures.

At *d* about three quarters of her enlightened hemisphere is visible to us, and she is then said to be *gibbous*.

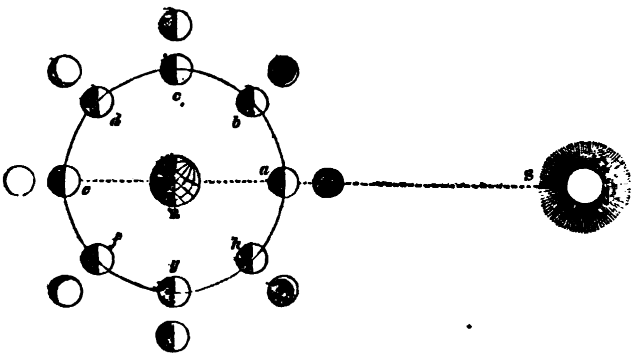


Fig. 16. The Moon's Phases.

At *e*, when she has completed one half of her revolution, the whole of her enlightened hemisphere is visible to us, and she is then *full moon*. In this position she is said to be in *oppositi n* to the sun. If the plane of the moon's orbit had exactly coincided with that of the earth's, she would have been invisible to us at this period, for, in this case, the earth would have obstructed the sun's light; but it so happens, that she is mostly either above or below the line connecting the earth and the sun, and hence it is that we usually see the whole of her enlightened face. This will be better understood when we come to consider the subject of eclipses.

At *f* she is gibbous, at *g* half moon, at *h* horned, and at *a* she again becomes invisible.

ECLIPSES.

38. An eclipse of the sun is called a *solar eclipse*, and that of the moon a *lunar eclipse*. When the moon comes between the earth and the sun, his light is obstructed, and an eclipse of the sun is produced; and an eclipse of the moon takes place when the earth is between the sun and the moon. Hence it is that *eclipses of the moon can only occur at her full*, or

when she is in opposition, and eclipses of the sun at her change, or when she is in conjunction; moreover, the three bodies must be in, or nearly in, the same straight line.

Now, if the moon's orbit were in the same plane as the ecliptic or path of the earth, then the sun would be eclipsed at every new moon, and the moon would be eclipsed at every full moon. But as her orbit is a little inclined to the earth's, she is mostly either above the ecliptic or below it when she is in opposition and conjunction. The points where the moon's orbit cuts the plane of the ecliptic are called the *nodes;* hence it follows that eclipses can only take place when the moon happens to be in or near one of the nodes at the moment she is in opposition or conjunction. In the course of a year there may be seven eclipses of the sun and moon — five of the sun and two of the moon, or four of the sun and three of the moon. Lunar and solar eclipses differ very much from each other in certain respects: a lunar eclipse may be seen at the same time by all persons to whom the moon is visible, whereas a solar eclipse may be seen by one person and not by another; again, an eclipse of the sun can never last more than eight minutes, whereas an eclipse of the moon frequently continues for more than two hours.

39. *Eclipse of the moon.* — If the whole disk or face of the moon is immersed in the shadow cast by the earth, then the eclipse is said to be *total;* and the eclipse is said to be *partial* when only a part of the disk is obscured.

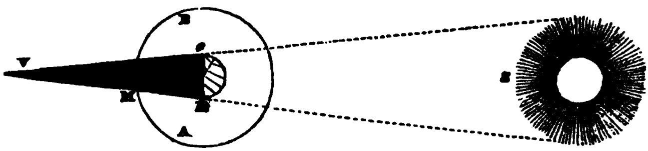


Fig. 17. Total Eclipse of the Moon.

In Fig. 17 a total eclipse of the moon is shown; S represents the sun; E *e* the earth; A B the moon's orbit round the earth; E *e* V the conical shadow cast by the earth; M the dark body of the moon totally immersed in this shadow.

It is always observed that the edge of the earth's shadow on the face of the moon is circular; now, this proves that the earth is a globe, for no body but a globe will always cast a circular shadow. Take an orange and hold it on a level with the flame of a candle; observe the shadow which is cast upon a sheet of paper held at different distances from the orange.

40. *Eclipse of the sun.* — A total eclipse of the sun takes place at that part of the earth's surface which is immersed in the moon's shadow.

Fig. 18 represents a total eclipse of the sun; where S represents the sun; E *e* the earth; A B the moon's orbit; M the moon exactly in a

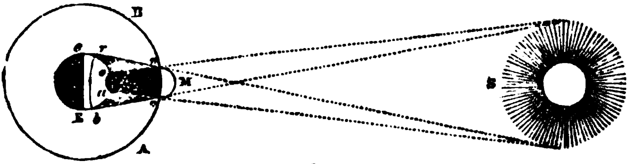


Fig. 18. Total Eclipse of the Sun.

line between the sun and the earth; *c n a o* the moon's shadow cast upon a small portion of the earth at *a o*: this dark shadow is called the *umbra*. The sun will appear totally eclipsed to persons living within *a o*; but to persons living without this portion, that is, between *a o* and E *e*, the sun will be visible. Between *a o* and *b r* the sun will be partially obscured: this portion of the shadow is called the *penumbra*, because it is not so dark as the umbra, or the portion in the full shadow.

Within the umbra, therefore, a total eclipse takes place; whereas within the penumbra the sun is only partially eclipsed.

41. *Annular eclipse.* — If the conical shadow of the moon does not reach the earth, then an *annular eclipse* will take

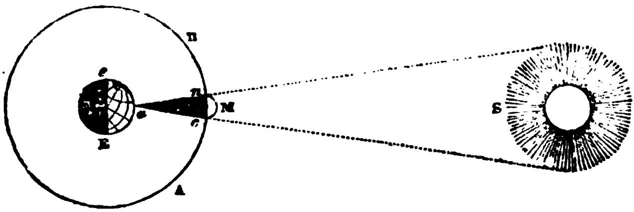


Fig. 19. Annular Eclipse.

place to all persons immediately below the vertex of the moon's shadow; that is, the moon will appear like a black spot upon the sun, surrounded by a *ring* of light.

Here the vertex of the moon's conical shadow does not reach the earth

at *a*; so that a spectator at *a* will see the moon like a dark spot nearly covering the sun's disk.

THE SUN AND PLANETS.

42. Having described the motions of the earth and the moon, we shall now treat of the sun, with the other bodies composing the solar system.

43. The planets are opaque bodies; that is to say, they do not emit any light of their own, but merely shine with the light borrowed from the sun. This is proved by means of the telescope, which shows that they present faces similar to the moon's, having their enlightened sides always turned towards the sun.

44. The planets are divided into inferior and superior: those which revolve *within* the earth's orbit are called *inferior planets*, and those which revolve *without* it are called *superior planets*. Thus Mercury and Venus are inferior planets, and Mars, Jupiter, Saturn, Uranus, and Neptune, together with the Asteroids, are superior planets. (See Fig. 3.)

APPARENT MOTIONS AND APPEARANCES OF THE PLANETS EXPLAINED.

45. Viewed from the sun, as the great centre of the solar system, the planets would appear to move round him in regular order and progression. But the case is very different when we view their motions from the earth, which also moves round the sun; at one time they appear to have a *progressive* or direct motion, that is, from west to east; then they appear *stationary*, or without any apparent motion; and at other times they appear to have a *retrograde* motion, that is, from east to west. They are sometimes in *conjunction* with the sun, and then they are generally lost in his superior light; and some of them (the superior planets) appear in *opposition* to the sun, that is, in the opposite point of the heavens.

In order to form a familiar idea of these motions, conceive yourself placed in the centre of a horse ring; the horse, as he moves round you, will appear to move in a regular and progressive manner: now, conceive yourself to be placed without the ring; then the motion of the horse appears no longer regular: at one time he appears to move say from right to left, then for a moment he appears as if he were stationary, and afterwards he appears to move from left to right, and in two points of his path he appears in conjunction, or, as it were, in the same place with the man in the centre of the ring. These apparent motions of the horse give a true representation of the apparent motions of the two inferior planets, Mercury and Venus.

46. *Opposition and conjunction of the planets.* — That Mercury and Venus are *inferior* planets is proved by their crossing the sun's disk like a black spot, thereby showing that they must revolve between us and the sun; whereas Mars and the other *superior* planets never do so. Moreover, Mercury and Venus never appear in opposition; whereas Mars and the other superior planets appear in opposition as well as in conjunction.

In Fig. 20 let S represent the sun; E the earth; V an inferior planet; and M a superior one. At *m* and *v* both planets appear in conjunction

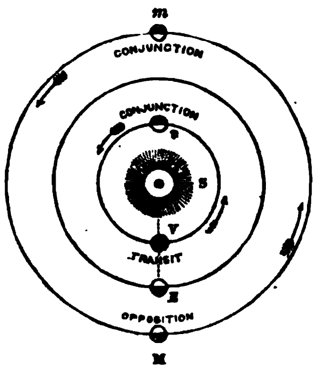


Fig. 20. Conjunction and Opposition.

to a spectator on the earth, but at M and V the superior planet M is in opposition, while the inferior planet V is in conjunction; and at this

position it will sometimes appear like a black spot crossing the sun's disk: this is called the *transit* of Venus, or Mercury, as the case may be: thus, while the superior planets never cross the sun's disk, the inferior ones never appear in opposition.

47. *Apparent motions of Venus.* — We shall now illustrate the cause of the apparent motions and phases of the planets by a reference to the planet Venus.

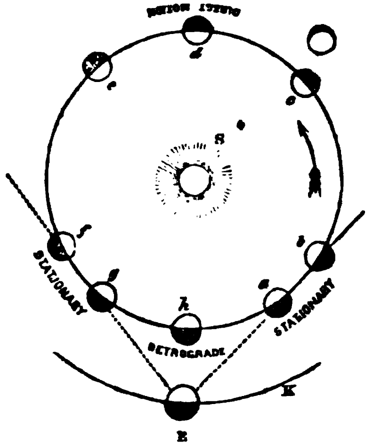


Fig. 21. Apparent Motions of Venus.

In Fig. 21, let S represent the sun; E the earth; *a b c d e f g h* the different positions of Venus in her orbit; E *a b* and E *g f* tangent lines drawn from the earth to the orbit of Venus. From *a* to *b*, the planet Venus appears *stationary*, that is, for a time she neither appears to move towards the west nor towards the east; in this position she has attained her greatest westerly distance, or *elongation*, from the sun. From *b* to *f* her motion is *direct*, that is, she appears to move amongst the stars from west to east. From *f* to *g* she is again *stationary*; and from *g* to *a* her motion is *retrograde*, that is, she appears to move from east to west. At *h*, in a line with the earth and sun, a transit takes place. Thus, in making an apparent revolution from *a* round the sun, she is first stationary, then she has a direct motion, next stationary, and, finally, she has a retrograde motion.

48. *Phases of Venus.* — Between *h* and *a*, (see Fig. 21,) her enlightened hemisphere appears to us like a *horned* moon; at *a* and *b* she presents the appearance of a *half moon*; at *c*, *gibbous*; and at *d*, *full moon*;

and so on. It is plain that if Venus had shone with her own light, she would always have appeared perfectly round to us.

49. *Morning and evening star.* — When Venus appears to the west of the sun, that is, from *d* to *h*, (see Fig. 21,) she is the evening star, for then she shines in the western sky at sunset; and on the contrary, when she appears to the east of the sun, that is, from *h* to *d*, she shines in the eastern sky before sunrise.

COMPARATIVE SIZE AND APPEARANCE OF THE PLANETS.

50. The following diagram exhibits the comparative size and appearance of the principal planets in the solar system.

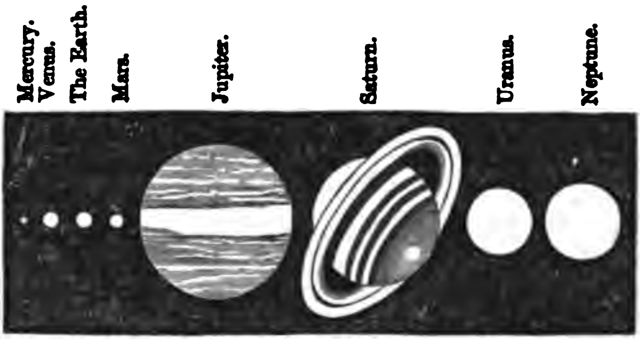


Fig. 22.

Jupiter is the largest of all the planets; his diameter is about 11 times the diameter of the earth; Saturn, Neptune, and Uranus are next in order of magnitude; the Earth and Venus are about the same size; the diameter of Mars is only about one half the diameter of the earth; and Mercury is about one third smaller than Mars. The Asteroids (which could not be shown in this diagram) are very small bodies, the largest of them not being more than 250 miles in diameter. The diameter of the sun is about 110 times the diameter of the earth, and his entire mass is vastly greater than that of all the planets put together. Constructed on the scale of the accompanying diagram, he would have been represented by a globe of about a foot in diameter.

TABULAR VIEW OF THE SOLAR SYSTEM.

	NAMES.	Diameter in Miles.	Distance from the Sun in Miles.	Time of Rotation on Axis.	Annual Revolution round the Sun in Days.
				H. M.	
	Sun,	882000	....	607 48?	
	Mercury,	3140	37 mill'ns.	24 5	87·969
	Venus.	7800	69 "	23 21	224·700
	Earth,	7926	95 "	24 0	365·256
	Mars,	4100	144 "	24 37	686·979
Asteroids.	Flora,	....	209 "	....	1193·249
	Vesta,	250?	225 "	....	1325·147
	Iris,	....	226 "	....	1341·636
	Metis,	....	227 "	....	1345·850
	Hebe,	....	230 "	....	1379·994
	Asterea,	....	244 "	....	1511·095
	Juno,	79?	250 "	27 0?	1594·296
	Ceres,	160?	260 "	....	1682·125
	Pallas.	....	261 "	....	1686·510
	Irene.*				
	Jupiter,	87000	490 "	9 56	4332·584
	Saturn,	79160	900 "	10 29	10759·219
	Uranus,	34500	1800 "	9 30?	30686·820
	Neptune,	41600	2850 "	....	60126·710

THE SUN.

51. This stupendous globe, nearly a million and a half times the bulk of our earth, is the great source of light and heat to all the planets, and by the attraction which he exerts retains them in their orbits. The telescope shows that there are dark spots upon his surface, and by observing them, astronomers have ascertained that he revolves on his axis every 25 days, in the same direction as the planets move round him, that is, from west to east.

MERCURY.

52. This little planet moves round the sun in about 88 days, at the distance of about 37,000,000 of miles, and revolves on his axis in 24 hours 5 minutes. The length of his day will, therefore, be rather more than ours, and the dura-

* Discovered by Mr. Hind, May 19, 1851. Three additional asteroids have been very recently discovered.

tion of his year about one fourth that of our year. The apparent motions, &c., of this planet are similar to those of Venus.

VENUS.

53. Of all the stars, this is the brightest and most beautiful. Her distance from the sun is about three fourths of the earth's distance, and hence she receives nearly double the light and heat from the sun.* She completes her revolution round the sun in about 225 days, and performs a rotation in 23 hours 21 minutes, on an axis inclined to the plane of her orbit at an angle of 15°. The length of her day is, therefore, nearly the same as ours, and the inclination of her axis shows that she has seasons similar to ours. She is surrounded by a large atmosphere, and from the irregularities observed on the edge of her crescent, it has been inferred that she has enormous mountains upon her surface, probably much larger than any on our earth.

MARS.

54. This small planet is about 1½ times the earth's distance from the sun; he takes about two of our years in revolving round the sun; and the length of his days is about the same as ours. The inclination of his axis to the plane of his orbit shows that he has seasons similar to those which take place on the earth. He is surrounded by an atmosphere, and the outline of continents and seas may be distinctly traced by means of a telescope. The red, fiery color of his light is supposed to be produced by the ochrey tinge of his soil, like that which red sandstone might produce. Bright white spots are seen about the poles, which are no doubt occasioned by the reflection of the sun's light from the polar snows and ice upon the planet; for it is observed that as each pole is turned towards the sun, the bright spots about it become less, owing to the melting of the snow by the sun's heat.

* The light and heat derived from a luminous body varies inversely as the squares of the distance: thus, taking the earth's distance from the sun as unity, we have heat of the earth : heat of Venus : : $(\frac{3}{4})^2 : 1^2$: : 9 : 16.

THE ASTEROIDS.

55. These bodies revolve round the sun, in orbits variously inclined to the ecliptic, between the orbits of Mars and Jupiter. They are so very small that their diameters have not yet been accurately determined. Some of them have very extensive atmospheres. They have all been discovered within the present century, and six of them have been discovered within the last six years.

JUPITER.

56. This is the largest of the planets. He takes about twelve years to complete his revolution round the sun, and turns upon his axis in about ten hours. This rapid rotation has caused him to be much flattened at the poles.

The disk of Jupiter is always found to be crossed with dark parallel bands or belts with spots, as shown in Fig. 22. Although these belts vary both in breadth and situation, yet they always run parallel to the equator of the planet; this appearance of the planet, no doubt, depends upon its atmosphere.

This magnificent planet has four moons, which constantly revolve about him from west to east, and accompany him in his path round the sun. Thus the satellites of Jupiter constitute a miniature system, to which their primary is the centre, in all respects similar to the solar system, of which their central body itself is only a member.

Three of Jupiter's satellites are totally eclipsed at every revolution, by the great shadow which he casts from the sun. These eclipses are of great use in finding the longitude of places upon the earth.

57. *Velocity of light.*—The eclipses of Jupiter's satellites have enabled astronomers to determine the velocity of light. When Jupiter is in opposition we are much nearer to him than when he is in conjunction; owing to this difference

of distance we see the eclipses of his satellites 16½ minutes sooner in the one position than we do in the other.

Let S represent the sun, (see Fig. 23;) J Jupiter; M the satellite eclipsed by the great conical shadow of the planet; E the position of the

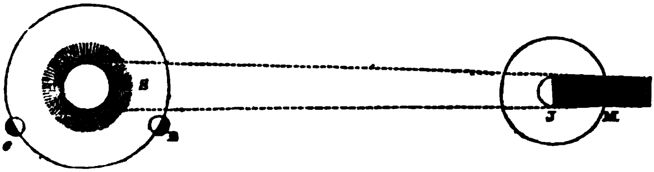


Fig. 23. Eclipse of Jupiter's Satellites.

earth when Jupiter is in or nearly in opposition; and *e* the position of the earth when he is in conjunction; then the distance between E *e* is equal to, or nearly equal to, the diameter of the earth's orbit. Now, the eclipse seen from E takes place 8¼ minutes before the calculated time, whereas when it is seen from *e* it takes place 8¼ minutes later than the calculated or true time; consequently the light takes 16½ minutes to travel from E to *e*; that is, *light takes* 16½ *minutes in traversing the diameter of the earth's orbit.*

SATURN.

58. Saturn's year is 29½ times the length of our year, and the length of his day is about 10½ hours. His distance from the sun is about 9½ times that of the earth. The diameter at his equator is about $\frac{1}{10}$ greater than the diameter at his poles. Like the earth, his axis is inclined to the plane of his orbit, and therefore he must have seasons. Saturn has eight satellites, seven of which had been known for sixty years before the eighth satellite was discovered. He is distinguished by having a thin broad ring surrounding his equator, as shown in Fig. 22. This ring is concluded to be opaque, because it casts a shadow on the surface of the planet; it is separated by different intervals, so that it is really a series of rings concentric with the planet; its whole breadth is 27,000 miles, and its thickness does not exceed 100 miles. The space between the inner side of the ring and the planet is 19,000

miles. The different parts of the ring revolve round Saturn in periods depending on their respective distances from him; the outermost ring revolves in about 10½ hours. Saturn has dark belts like Jupiter, but rather broader and less strongly marked; the cause of these belts is no doubt atmospheric, as in the case of the belts of Jupiter.

URANUS.

59. This planet completes his revolution round the sun in rather more than eighty-four years; his mean distance from the sun is about nineteen times that of the earth. The discoverer of Uranus, Sir W. Herschel, believed that this planet had six moons; but only two have been observed by other astronomers. The motion of these satellites, round their primary is from east to west, which is an exception to the law observed by the satellites of Jupiter, Saturn, and the Earth.

NEPTUNE.

60. Neptune, the most remote planet at present known in the solar system, completes his revolution round the sun in about 166 years, at about thirty times the distance of the earth from the sun. One satellite has already been observed, revolving round the planet at the distance of about twelve of its radii. This planet was discovered in 1846, and its existence was determined by calculations, based upon the law of gravitation, before it had been recognized as a planetary body by observation. This may be regarded as one of the greatest achievements of mathematical science.

COMETS.

61. Upwards of 130 comets have been observed at different times, but only three have been identified as having been seen before. The comet which was seen in 1835, called Halley's comet, revolves round the sun in about seventy-six years.

Their orbits are ellipses or ovals, so very flat or eccentric, that the comets are invisible to us for the greater part of their revolutions round the sun.

Comets are not solid like the planets; they merely consist of a mass of vapor, the central portion of which is called the *nucleus*, or head, being more dense than the rest. Sometimes this vapor extends to a great distance in the form of a *tail*, which is always in a direction contrary to the sun.

THE PLANETS MOVE IN ELLIPSES.

62. The true path of the planets round the sun are ellipses or ovals, differing in general but little from circles, of which the sun occupies what is called the focus.

Thus, in Fig. 24, E represents the earth; E D A its elliptical orbit round the sun; S the sun in the focus of the ellipse.

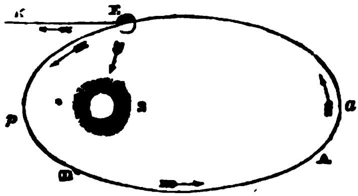


Fig. 24. Elliptical Orbit.

Kepler discovered the elliptical motion of the planets, with other important facts, by observation, and Newton showed, by mathematical analysis, that this peculiar form of their orbits depends upon a certain law of the attractive force residing in the sun, called the law of gravitation.

When the earth is nearest the sun, as at *p*, it is said to be in its *perihelion;* and when the earth is farthest from the sun, as at *a*, it is said to be in its *aphelion*. The motion of the earth in its orbit is quickest when it is nearest the sun, or in its perihelion, and slowest when it is farthest from the sun, or in its aphelion. Hence it is that the time between our vernal and autumnal equinoxes is about eight days longer than the time between our autumnal and vernal equinoxes; thereby causing the summer in the northern hemisphere to be a little

longer than the winter. The earth is about three millions of miles nearer to the sun in winter than it is in summer. If this be the case, it may be asked, Why is our summer so much warmer than our winter? If we are nearer to the sun in winter than we are in summer, why should it not be warmer in winter, rather than colder? It is quite true that this would be the case, were it not for other causes, which far more than counterbalance the very small deficiency of temperature arising from this difference of distance from the sun. These causes have been briefly and incidentally explained in Art. 30, but it may be instructive to bring them here before the student in a distinct form.

Heat of Summer.

The days in our summer months being very much longer than they are in our winter months, we must manifestly receive much more heat from the sun during the former period than we do during the latter.

In our summer the sun rises to a much greater height above the horizon than he does during our winter, and consequently he not only continues longer above the horizon, but his rays, coming more perpendicularly, strike in greater numbers upon any given portion of the earth's surface.

Let A B represent a portion of the earth's surface, upon which the rays

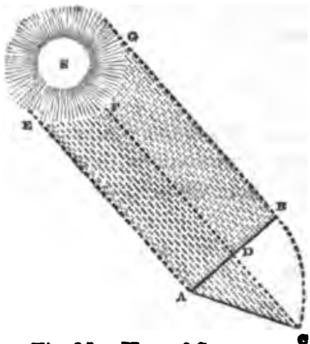


Fig. 25. Heat of Summer.

of the sun, A B G E, fall perpendicularly; and let A C be an equal portion of the earth's surface, upon which the rays of the sun, A C F E, fall obliquely, or in a slanting direction. Now, although the surfaces A B and A C are equal, yet it is plain that a much greater number of rays must fall on A B than upon A C: the rays of light and heat falling upon A B are included by the space A B G E, whereas those which fall on A C are included by the space A D F E: in fact the heat which falls upon the small portion A D is spread out over A C.

GRAVITATION.

63. When a body moves in a curved line, such as the path of the earth round the sun, it must be under the action of two forces, one an impulsive force, or force of projection, the other a constantly acting force, such as the attraction of gravitation.

We have a familiar instance of this when a stone is projected obliquely upwards from the top of a high tower; the stone moves in a curve, called a parabola, in consequence of the motion of projection and the attraction of the earth. Now, as we increase the force of projection, the stone will be longer before it reaches the earth's surface; indeed, it is not difficult to conceive the force of projection to become so great that the stone shall not return to the earth's surface at all, but shall move round the earth like a little satellite similar to the moon.

The earth and all the other planets had at first a motion of projection given to them; and this motion would have carried them away into infinite space, had it not been for the sun's attraction. If the attractive force of the sun were to cease, the earth at E (see Fig. 24) would fly off from its orbit in the tangent line E K; and on the contrary, if the motion of projection were stopped, the earth would be drawn in towards the sun; but the two forces of projection and gravitation are so nicely adjusted, that the earth continually moves round its great centre of attraction, in an elliptical orbit, constantly returning at every revolution (at least virtually) to the point from which it started. This law of gravitation,* which holds true with respect to the sun and the planets, also holds true with respect to the motion of the satellites round their respective primaries.

* According to the law of gravitation, (1.) All bodies attract one another with forces proportional to the masses of matter which they contain; (2.) The force of attraction decreases as the squares of the distances increase.

ATMOSPHERIC REFRACTION.

64. The atmosphere which surrounds the earth is of variable density; that is, the higher we ascend the rarer it becomes. It may therefore be considered as consisting of a series of strata or layers K G I M, G D F I, D A C F, &c., (see Fig. 26,) of decreasing density. Now, air, as well as all transparent substances, possesses the power of *refracting* the rays of light, or bending them out of their straight course; thus the rays of light proceeding from a star, or any heavenly body, become bent more and more downwards as they pass through the atmosphere, and the star is seen, not in the direction in which it actually lies, but in the direction which these rays have at the instant of arriving at the eye of an observer: the effect of this is, to cause the star to appear higher in the heavens than it really is.

In Fig. 26, let S represent a star beyond the limits of the atmosphere K A C M; S B is the straight course of a ray of light proceeding from

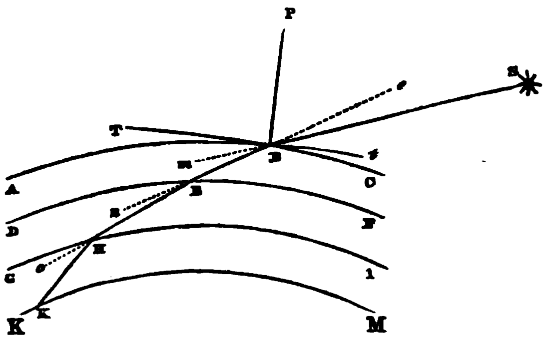


Fig. 26. Refraction.

the star. In passing through the layer of atmosphere A C F D, the ray S B is bent down into the direction B E; now, if the next layer D F I G were of the same density as A C F D, the ray B E would proceed in the straight line B E *n*; but as the former is denser than the latter, the ray is bent down into the direction E H; and so on through every successive

layer, until the ray comes to the eye of the observer. As the ray of light proceeds downwards, the strata of air become more and more dense, which causes the ray to become more and more bent in its passage; hence it is that the course of the refracted ray through the atmosphere is that of a curve, which becomes more and more concave as it approaches the earth, as shown in Fig. 27; where M is the luminous object; M *a* the straight

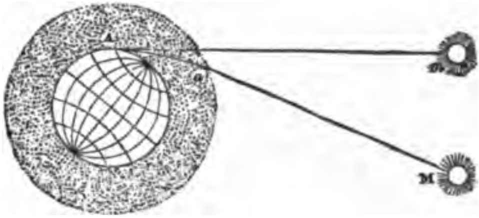


Fig. 27. Atmospheric Refraction.

direction of the rays of light, which, meeting the atmosphere at *a*, are by refraction bent into the curve *a* A; A *m* is the direction which the refracted ray has when it arrives at the eye of the observer at A; and A *m* is the direction in which the star will be seen: thus the refraction of the atmosphere causes us to see the heavenly bodies apparently higher above the horizon than they are in reality. The body M may actually be beneath the horizon, and yet be visible to a person at A.

The atmospheric refraction elevates the apparent position of the heavenly bodies most when they are near the horizon; and at the zenith it does not affect their position at all.

OVAL FORM OF THE SUN AND MOON NEAR THE HORIZON.

65. This remarkable appearance is occasioned by atmospheric refraction. The upper half of the sun or moon's disk, as the case may be, being less raised by refraction than the lower half, causes the vertical diameter of the disk to be lessened, while the horizontal diameter remains unchanged; hence the disk appears of an oval shape.

TWILIGHT.

66. Twilight is that light which we enjoy for about an hour and a half before the sun has appeared above the horizon, and

for about the same time after he has set. This beautiful law of nature is caused by the *reflection* of the sun's light from the higher regions of the atmosphere. Some time before we have any direct transmission of light from the sun, his beams illuminate the higher portions of the atmosphere, and then this illuminated portion transmits light to us.

In Fig. 28, let G A E represent the earth; G K C D E a portion of its atmosphere; A the place of an observer; A R his horizon; and S the sun considerably below the horizon, and of course invisible to a person

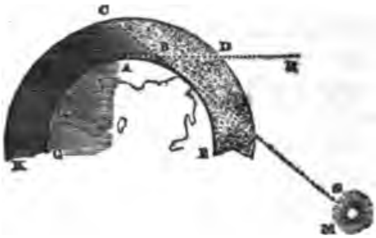


Fig. 28. Cause of Twilight.

at A. Now, that portion of the atmosphere represented by C B E D will be illuminated by the sun, while A C K G will be in comparative darkness; and the illuminated portion C B D will be visible to a person at A, and the light proceeding from it will occasion his twilight. The duration of twilight varies with the latitude and the season of the year. At the equator the duration of twilight is always short, whereas at the poles it lasts for upwards of four months. Twilight begins in the morning, and ends in the evening, when the sun is about eighteen degrees below the horizon.

THE TIDES.

67. The alternate flowing and ebbing of the sea is called the tides. They are produced by the attraction of the sun and the moon upon the waters of the ocean, but chiefly by the attraction of the moon; for as she is much nearer to the earth than the sun, her attractive force upon the waters is considerably greater than that of the sun's.

For a little more than six hours, the sea, in certain places,

gradually swells and then flows into harbors and the mouths of rivers; this is called *flood tide.* At the end of this time the ocean has attained its greatest height; this is called *high water.* The waters then begin to *ebb* or fall, which they continue to do for a little more than six hours, until they arrive at their lowest level; this is called *low water.* Thus the waters of the ocean, day after day, alternately swell and fall in a little more than six hours; so that high water takes place twice in every 24 hours 50 minutes, this being the time which the moon takes in passing from the meridian of a place, to returning to the same meridian again. If the moon were stationary, the interval between high water of one day and high water the next would be exactly 24 hours; for the same part of the earth would return to the moon's meridian in this time; but while the earth is performing a revolution on its axis, the moon advances about 13° in her orbit, so that it takes the earth about 50 minutes more to bring the same place opposite to, or on the same meridian with, the moon.

68. In explaining the cause of the tides, we shall first speak of the moon's attraction alone. If the earth were an exact sphere covered with water, and if there were no external attraction exerted upon it, the water would arrange itself uniformly over the surface, forming a coating like the rind of an orange; but when the earth is brought under the influence of an attractive body, like the moon, this uniformity in the distribution of the water no longer subsists.

In Fig. 29, let E represent the earth surrounded by water; M the moon; and S the sun; then, since the moon's attraction is greatest upon the objects which lie nearest to her, the water at *a*, directly below the moon, will be more attracted by her than the water which lies farther off; hence it is plain that the water at *a*, beneath the moon, must be drawn up, or, as it were, heaped up; now, as the earth revolves on its axis, successive parts of its surface must pass under the moon, and these parts will have high water in regular succession. But for a similar reason there will also be high water at *c* on the opposite side of the earth; for the water at *c* must be less drawn towards the moon than the water at *b* or *d*, or any parts between *c* and *b*, or *c* and *d*; hence it follows that

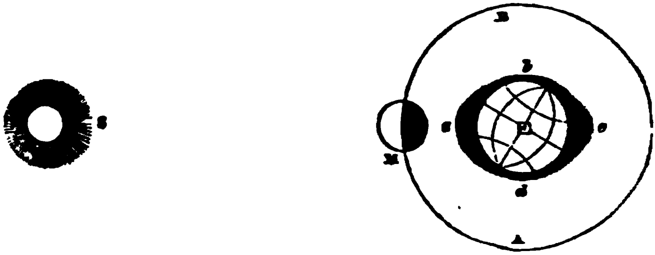


Fig. 29. Spring Tide at New Moon.

the water must be heaped up towards *c*. At *b* and *d* there will be low water.

It will now be readily seen why we have twice high water and twice low water in the course of every 24 hours 50 minutes.*

69. We have hitherto regarded the attraction of the moon alone as the cause of the tides; but this is not strictly true, for the sun's attraction very much affects the magnitude of the tides.

The largest tides take place when the moon is at her change, or at her full moon; for in both these cases the attractive forces of the sun and moon combine in raising the waters; these are called *spring tides*. On the contrary, the lowest tides take place when the moon is at the beginning of her second and fourth quarters, that is to say, when she is half moon; for then the attractive forces of the sun and moon act so as to diminish each other's effect; these are called *neap tides*.

Fig. 29 represents *the spring tide at new moon*. Here the attractive forces of the sun and moon obviously coöperate in raising the waters of the ocean at *a* and *c*.

* It must be observed that the tide is not at its highest when directly under the moon, but about two hours later; for since the full effect of the moon's attraction on the waters is not instantaneous, high water will not take place until the moon has passed the meridian: in the same way, the hottest part of the day does not take place till some time after noon; and also the month of July is always hotter than the month of June.

Fig. 30 represents *the spring tide at full moon;* where S represents the sun, M the moon at her full, and E the earth. Here the attractive

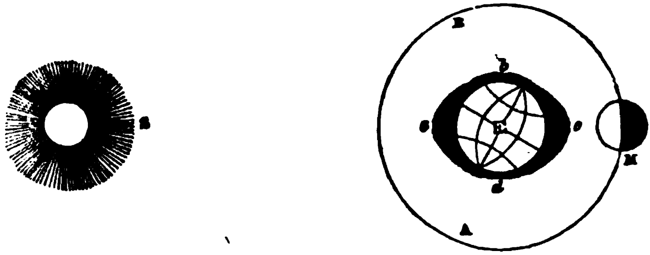


Fig. 30. Spring Tide at Full Moon.

forces of both the sun and the moon tend to draw the waters away from *b* and *d*, and to accumulate them, or heap them up, at *a* and *c*.

Fig. 31 represents *the neap tides at half moon;* where M represents the moon, either at the beginning of her second or at the beginning of

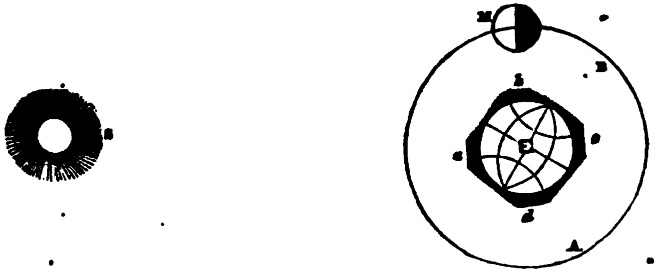


Fig. 31. Neap Tides.

her fourth quarter. Here the attraction of the sun tends to diminish the flow of the waters at *b* and *d*, and hence the tides at these periods are smaller than at any other.

Thus in the course of a lunar month we have two spring tides and two neap tides.

THE FIXED STARS.

NUMBER OF THE FIXED STARS.

70. The number of the fixed stars exceeds all computation. Viewed through a powerful telescope, *the milky way*, or *galaxy*,

appears like great groups of constellations. Dr. Herschel counted 600 stars within the view of his telescope at one time; and in one portion of the milky way, he computed that the number of stars exceeded a quarter of a million. But if the power of our telescopes were still further increased, there would be no limit to the number of stars which we might observe.

DISTANCE OF THE FIXED STARS.

71. It has been ascertained that the nearest of the fixed stars are at such enormous distances from us, that it would take their light, travelling at the rate of twelve millions of miles in a minute, at least six years in reaching us. The truth of this may be illustrated in the following manner: —

Look at two trees at no great distance from you, and observe the apparent distance between them; now change your position, by walking either to the left or to the right, and observe that the apparent distance between the trees is decidedly changed; indeed, you may come to a position where the two trees would appear as one, or, more correctly speaking, in the same straight line. Here, then, we conclude that when objects are near to us, their apparent distances from one another are very much affected by our change of position. Again, proceeding in the same manner, look at two objects more remote from you; then you will find that your change of position scarcely at all alters the apparent distances of the objects. Here, then, we conclude, that when objects are very distant from us, their apparent distances from one another are very little affected by our change of position. Now, the earth, as it revolves round the sun, undergoes a change of position measured by the diameter of its orbit, or 192 millions of miles. The earth, therefore, is 192 millions of miles nearer to certain fixed stars at one time than another; yet, notwithstanding this enormous change of position, there is scarcely any difference observed in the apparent distances of the stars from one another. How immensely great, then, must their distances be from us! *

* Astronomical instruments have been made with such nicety, that a difference may be detected in the apparent distances of two objects, when their distance from us is 100,000 times the distance between the two points of observation. But as only a very minute difference can be detected by our best instruments in the apparent distances of the stars when viewed from

THE STARS HAVE MOTION.

72. The stars have a motion through space: thus, for example, a small star in the constellation of the Swan has been found to move annually over five seconds of the arc of the heavens. Now, according to Arago, the distance of this star from us is not less than 400,000 times the distance of the earth from the sun: in order, therefore, that this star should move over five seconds annually, it must actually travel many millions of miles in this time. Hence it is only in a relative sense that we can speak of the stars as being fixed; absolutely considered, there is probably nothing fixed in the universe.

MULTIPLE STARS. — GRAVITATION EXTENDS TO THE STARS.

73. Certain stars, although they appear single to the naked eye, are found to be double or treble stars when viewed through a good telescope. Stars of this kind are very numerous; in 120,000 stars examined by M. Struve, one in every forty was found to be a multiple star, that is, a group of two, three, or even four stars; indeed, it seems probable that, were our telescopes sufficiently powerful, we should find all the stars which appear single to the naked eye to be really groups of stars.

74. In these multiple stars one is always observed to be much more brilliant than the rest. This brilliant star in each group is the central sun, round which the others revolve, in the same manner as the planets in our system revolve round the sun. These multiple stars, therefore, are systems of

the opposite points of the earth's orbit, it follows that the nearest stars must be at least 100,000 times 192 millions of miles from us. Mr. Henderson discovered that the star called Centauri is altered in its apparent position by only about one second; assuming this to be the case, the distance of this star from us must be about half a million of times the earth's distance from the sun. This angular change in position is called the parallax of the star. Not more than ten stars have at present been found to have any parallax; and that of the star Centauri is the greatest which has yet been observed.

worlds similar to our solar system, thereby proving that the law of gravitation, which animates and controls the planetary bodies, exists throughout the remote regions of the celestial spaces. How beautiful it is thus to mark the unity of plan manifested in the constitution of the universe: the law of attraction which causes a stone to fall to the ground, which gives the globular form to the mass of the earth, and which guides the planets in their motion round the sun, — that same law binds the stars to one another, in each group of multiple stars; and it may not be improbable that all these worlds and systems of worlds which people the immensity of space are but parts of one grand integral system, which, under the great controlling principle of gravitation, are linked to one another, as well as to one vast central mass, fixed in the unfathomed depths of the universe.

> "That very law which moulds a tear,
> And bids it trickle from its source, —
> That law preserves the earth a sphere,
> And guides the planets in their course."

THE DIVISIONS OF TIME. — THE CALENDAR.

75. The motions of the sun and moon have been taken in all ages as the measure of time. The diurnal motion of the sun is the measure of our day; his revolution in the ecliptic gives the length of our year; and the periodic return of new moon is the basis of our division of time into months.

ASTRONOMICAL AND SIDEREAL DAY.

76. The *astronomical day* is 24 hours long; it is the mean of the intervals between the noon of one day and the noon of the succeeding one.

The period which the earth takes to revolve on its axis is constantly the same; viz., 23 hours, 56 minutes, 4 seconds. This is called a *sidereal day*, for it is the time which any me-

ridian on the earth takes in revolving from a fixed star to that star again.

The astronomical day is nearly four minutes longer than the sidereal day. This is caused by the sun's motion in the ecliptic; for while the earth is turning on its axis, the sun is advancing amongst the stars, and hence it requires the earth to make rather more than a complete revolution to bring the same meridian under him.

EQUATION OF TIME.

77. Owing to certain causes,* which need not at present be explained, the sun does not move uniformly amongst the stars; and hence we find that the interval between two successive noons is not always the same. A clock, therefore, which keeps true time will not always correspond with the time as indicated by the sun. Thus, for example, if it be 12 o'clock to-day by a watch keeping true time, when the sun is exactly at noon or on the meridian, then it will not be exactly 12 o'clock by the watch to-morrow when the sun is on the meridian; the time by the watch may be a little before or after 12 o'clock, according to the season of the year. This difference of time between the clock and the sun is called *the equation of time.* Almanacks contain the amount of this difference for every day of the year, so that we can always tell how much before or after 12 o'clock the sun will be on the meridian on any proposed day.

SOLAR YEAR.—JULIAN CALENDAR.

78. As the return of the sun to the same meridian marks the length of the day, so the return of the sun to the same equinox gives the length of the year.

* The irregularity of the sun's apparent motion arises from the following causes: First, upon the inclination of the ecliptic, or sun's apparent path, to the plane of the equator; and secondly, upon the elliptic form of the earth's orbit, which occasions the earth to move quicker when in the perihelion, or nearest the sun, and slower when in the aphelion, or farthest from the sun.

The solar year contains 365 days, 5 hours, 48 seconds, or 365 days, 6 hours, nearly. But as the common or civil year consists of only 365 days, the solar year is about a quarter of a day longer than the civil year; and therefore, if this year always contained 365 days, there would be an error of a day committed in the course of every four years. Now, in order to correct this error, Julius Cæsar, the great Roman general, enacted that every fourth year should consist of 366 days; this year is called leap year, and the additional day is added to the month of February, which therefore consists of 29 days in leap year. This mode of reckoning is called the *Julian calendar.*

GREGORIAN CALENDAR.

79. Now, if the solar year had consisted of 365 days, 6 hours, exactly, no further correction would have been necessary; but this is about 11 minutes too much, and consequently the Julian calendar introduced an error of 44 minutes every 4 years, or about a whole day in 130 years. This error in the course of centuries became considerable. Thus, in the year 1577, the vernal equinox happened on the 11th of March in the place of the 21st. Pope Gregory, in the year 1582, corrected the calendar in the following manner: The 5th of October was called the 15th, to correct the error which had been committed since the time of Julius Cæsar; and to prevent the error happening again, it was agreed that every fourth year should be leap year, as in the Julian calendar, excepting that every hundredth year for three successive centuries, should be common years, and the fourth hundredth should be a leap year. Thus 1700, 1800, and 1900, are common years, and 2000 is a leap year. By this mode of reckoning, the error in 4000 years will not exceed one day. This is called the *Gregorian calendar.*

The Julian calendar is called *the old style*, and that of the Gregorian *the new style.*

The Gregorian calendar was at once received by all Roman

Catholic countries; but it was not adopted in this country until the year 1752. The Russians, and other members of the Greek church, still adhere to the old style, or the Julian calendar.

MODEL EXERCISES.

These questions are not only intended to give an analysis of the matter going before, but also, by a suggestive course of reasoning, to lead the pupil to reflect and reason upon the knowledge which has been communicated to him, and even in some cases to extend it.

THE STARS.

Teacher. What is the point directly over our heads called?

Pupil. The zenith.

T. What do you mean by the horizon?

P. That line all round us where the sky and the earth appear to meet.

T. What shape does the horizon appear to have?

P. It has a circular shape, and bounds our view on all sides.

T. What point in the heavens is that which lies directly below our feet?

P. It is called the nadir.

T. What would our zenith be to a person living on the opposite side of the earth?

P. It would be his nadir.

T. If I cut a globe (say an orange) into two equal parts, what is each part called?

P. Each part is called a hemisphere, or half sphere.

T. What do the heavens appear like?

P. A vast dome, or concave hemisphere.

T. Why do we not see the stars during the day?

P. Because of the superior light of the sun.

The teacher should continue to give questions of this kind, taking care to vary their form, until the pupil is thoroughly master of the subject.

CARDINAL POINTS.

Teacher. In what part of the heavens does the sun rise?

Pupil. He rises in the east, and sets in the west.

T. At noon the sun shines exactly upon the front of my house; now tell me the direction of the front wall of my house.

P. It must lie in a line extending from east to west.

T. What would be the direction of each gable in this case?

P. Each gable wall would lie in a line extending from south to north.

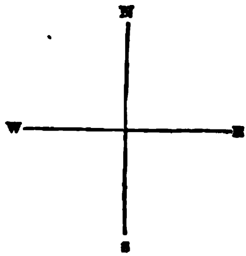


Fig. 32. The Cardinal Points.

T. If the line N S lies north and south, and E W lies east and west, how do these lines lie with respect to each other?

P. They lie at right angles to each other; that is, W E is at right angles to N S; or, in other words, W E is perpendicular to N S.

T. Describe the cardinal points in a map.

P. The top is north, the bottom south, the right hand east, and the left hand west.

T. What will be the direction of your shadow when you go home to-night, supposing the sun to be shining?

P. It will be cast towards the east.

And so on.

DIURNAL MOTION OF THE HEAVENS.—MAGNITUDE OF THE STARS.

Teacher. What is meant by the diurnal motion of the heavens?

Pupil. The daily revolution of the heavens about the polar star.

T. In what direction does this apparent motion take place?

P. From east to west. (Why?) Because the stars appear to rise in the east and set in the west.

T. What do you mean by a body having an *apparent* motion?

P. When a body appears to us as if it moved, without really doing so, we may say that its motion is only apparent.

T. How many stars may be seen with the naked eye?

P. About two thousand.

T. What stars are said to be of the first magnitude?

P. The largest and brightest.

T. What stars belong to the sixth magnitude?

P. Those which are just visible to the naked eye.

Proceed with the remainder in the same manner.

FIXED STARS AND PLANETS. — CONSTELLATIONS. — SIGNS OF THE ZODIAC.

Teacher. What are fixed stars?

Pupil. Those stars which do not change their distances from one another.

T. What are those stars called which do not always remain in the same place?

P. They are called planets.

T. Which stars twinkle most?

P. The fixed stars.

T. What do the planets look like when viewed through a good telescope?

P. They look like little luminous balls.

T. What is a constellation?

P. A constellation is a group of stars.

T. What is meant by the two pointers in Charles's Wain?

P. Those two stars in the back of the supposed wagon, which nearly point towards the polar star.

T. What is a celestial globe?

P. A celestial globe represents the appearance of the heavens, with the different stars and constellations marked upon it.

T. What is the upper star in the pointers called?

P. It is called Dubhe.

T. Through what portion of the heavens do the planets appear to move?

P. Through a belt or band of stars, containing 12 constellations, called the signs of the zodiac.

T. What is the ecliptic in the heavens?

P. It is the apparent annual path of the sun. It is marked out by the constellations of the zodiac.

T. Why was the term zodiac given to these constellations? Can you name the signs of the zodiac?

GENERAL PRINCIPLES OF ASTRONOMY.

Teacher. Objects appear to us to become less and less as they are removed from us. Give some familiar illustration of this. Describe the appearance of a balloon as it ascends.

Pupil. As the balloon rises in the air, it appears to us to become smaller and smaller, until at length it gets so far away from us as to appear very little larger than a foot ball.

T. In order, therefore, to know the real size of a body, we must not only observe its apparent size, but we must also know its distance from us. Now, let there be two trees of the same height, and suppose one of them to be at double the distance of the other; what would be their apparent magnitude?

P. The more distant tree would appear only about half the size of the other.

T. What is the moon?

P. A great globe, not very much smaller than the earth.

T. Why does she appear so small to us?

P. Because she is many thousands of miles from us.

T. If a balloon were 10 miles from us, how would it appear?

P. I should say that we could not see it at all; or, in other words, it would be invisible.

T. When a body appears to move, this appearance may be produced in two ways; what are they?

P. First, the apparent motion may be produced by the body actually moving in the direction in which we think it moves; and secondly, it may be produced by our having a motion in a direction contrary to that in which the body appears to move.

T. What have you to say relative to the appearance of objects when you are moving in a railway carriage? The heavens appear to turn round in every 24 hours; how may this be explained? What is the shape of the earth? In what time does it turn upon its axis? What does this motion of the earth give rise to? *

T. Give me a familiar instance of a body turning or spinning round on an axis.

P. A spinning top.

T. Where is the axis in this case?

P. It is the line round which it appears to spin.

T. The earth moves round the sun in the course of a year; how does this affect the appearance of the sun?

P. It gives rise to the *apparent* motion of the sun in the ecliptic.

* The pupil is supposed to answer these questions in succession.

T. What are the planets? What do they revolve round? What is the sun to them? Whence do they derive their light and heat? What is the path of a planet round the sun called?

SOLAR SYSTEM.

Teacher. Give a familiar example of one body revolving round another.

Pupil. A horse revolving round a man in the centre of a ring.

T. Of what does the solar system consist? In what direction do the leading planets revolve round the sun? In what plane do the orbits of the planets nearly lie? In what direction do they spin round on their axes? Name the planets in the order of their distances from the sun. What is a satellite? How many primary planets are there at present known in the solar system? How many satellites are there? Mention the number of satellites which respectively revolve round the different planets, &c.

T. If I move this orange round a candle, what would this rudely represent?

P. We may consider the candle as the sun, and the orange as a planet moving round him in its orbit.

T. Now, while I keep the orange moving round the candle, suppose I move this nut round the orange in such a manner that the nut shall make about 12 revolutions round the orange while the orange makes one revolution round the candle; what would this rudely represent.

P. It would represent the motion of the earth round the sun, and at the same time the motion of the moon round the earth.

T. What are comets? Who first taught correct views relative to the solar system? Who was Pythagoras? Who revived the system first taught by Pythagoras?

THE EARTH AND ITS MOTION.—FORM AND SIZE OF THE EARTH.

Teacher. Who first sailed round the world?

Pupil. Magellan.

T. Who first made the attempt?

P. Columbus.

T. If the earth were an unbounded flat surface, what would be the consequence of a vessel constantly sailing from any place?

P. The farther the vessel sailed, the farther she would get away from the place.

T. But ships never sail in a direct line from any place; how then can they be said to sail constantly in the same direction?

P. Ships may sometimes go to the right or to the left of their direct course, yet still they pursue a certain general direction.

T. Just in the same way, you might say, that a little fly may move round *this globe*,* though the creature may go in a zigzag course. Why do we not see the hull when a ship has sailed some distance from us?

P. Because the round part of the earth's surface comes between us and the hull.

T. After the hull of a ship has disappeared, what should you do to get a sight of it again?

P. I should get to the top of some high tower or hill.

T. What is the shape of the earth?

P. It is the shape of a ball or globe.

T. Some boy, I think, just said that the earth is round. Now, the upper part of my hat is *round;* is the earth, then, the shape of my hat?

P. Surely not; the earth is *round in every direction*, but your hat is round only in one direction.

T. What shape does my hat now *appear* to have?

P. A sort of oblong shape.

T. How do you know that the earth is round in every direction?

P. Because, wherever we may be, we always find that the horizon has a round shape; which shows that the earth must be every where round to present this appearance.

T. What do you think that seamen do when they want to observe a distant sail?

P. They climb to the topmast.

T. Why?

P. That they may see a greater way over the ocean.

T. (Moving his finger round the globe.) What has my finger moved over?

P. The circumference of that globe.

T. What is a line going through the globe called?

P. The diameter.

T. If the line only went to the centre, what would it then be called?

P. The radius.

T. What part of the diameter is the radius?

* In giving these lessons, the teacher must be provided with a small white globe, having a rod passing through it to represent the axis of the earth; and having also all the essential lines upon the terrestrial globe, painted in strong black lines.

P. One half.

T. Now, in this globe, every point on the surface is at the same distance from the centre. What have you, then, to say respecting the radii of a globe?

P. That they are all equal to each other.

T. How many times is the circumference of a globe greater than the diameter?

P. A little more than three times.*

T. If the length of a line stretching from London to York be 200 miles, how many times must this line be repeated to go round the earth?

P. About 125 times; because 25,000 divided by 200 gives 125.

T. How long will it take a man to walk round the earth, supposing that he travels 25 miles every day?

P. About 1000 days, or nearly three years; because the number of miles travelled per day = 25 miles.

DIURNAL MOTION OF THE EARTH.—LINES UPON THE GLOBE.

Teacher. How much of the earth's surface does the sun enlighten at one time?

Pupil. One half.

T. By what means is every part of the earth's surface brought within the light and heat of the sun?

P. The earth is made to turn round upon its axis in the course of every day.

T. (Turning a globe round.) Now, where is the axis in this revolving globe? Is there a real axis, or only an imaginary one?

P. The axis is only imaginary, and it is the line about which the globe appears to turn.

T. What have you now to say respecting the axis of the earth?

P. That it is the line about which the earth appears to turn.

T. What are the poles upon the earth?

P. The two points where this imaginary axis meets the earth's surface.

T. On what point is my finger now placed?

P. On the north pole.

T. (Tracing the equator with his pointer.) What is this line called, and how is it placed with respect to the poles?

P. It is called the equator, and lies at the same distance from either of the poles.

* The ratio commonly given is 3·1416.

T. How does the equator divide the globe?

P. Into two equal parts. One is called the northern hemisphere, and the other the southern hemisphere.

T. Upon what hemisphere is my hand now placed?

P. The northern hemisphere.

T. Is there any other way in which the changes of day and night might be produced?

P. Yes; the sun might turn round the earth in the course of a day.

T. If a poor woman wanted to roast a joint of mutton before the fire, what would she do in order to have every part equally roasted?

P. She would tie a piece of string to the mutton, and make it spin round before the fire.

T. Is there any other way in which this might be done? Now think.

P. The fire might be made to turn round the meat.

T. But which of these methods is the better?

P. The first method, certainly; because it must be far less trouble to make the meat turn round before the fire than to make a machine for turning the fire round the meat.

T. What should you say if a man proposed to do this?

P. That although he might show some ingenuity, yet he would be a very foolish person.

T. Now, it is equally ridiculous to suppose that the sun turns round the earth. It is too monstrous for us to conceive it possible that Almighty God, who is the fountain of all wisdom and goodness, could effect any of his purposes by the agency of means which it would appear unsuitable, even on the part of his creatures, to employ.

LATITUDE AND LONGITUDE.

Teacher. (Moving his pointer round the globe.) How many degrees have I moved my pointer over?

Pupil. 360°.

T. (Moving his pointer from the pole to the equator.) How many degrees have I now moved my pointer over?

P. 90°, or a quadrant.

T. Why?

P. Because it is a quarter of the whole circumference, and the quarter of 360° will be 90°.

T. Now, knowing the circumference of the earth to be 25,000 miles, I want you to tell me the length of 1°?

P. About 09½ miles; because, the length of the whole circumference, or 360°, being 25,000 miles, the length of 1° will be the 360th part of 25,000 miles, or 69½ miles nearly.

T. (Moving his pointer over a meridian.) What is this line called?

P. It is a meridian.

T. (Moving his pointer on the equator, between the first meridian and the meridian passing through a place.) What is this distance called?

P. The longitude of the place through which the meridian passes.

T. (Putting his pointer on a place in North America.) What kind of longitude will this place have?

P. West longitude.

T. (Moving his pointer on a parallel of latitude.) What is this line called?

P. A parallel of latitude.

T. Why is it called a *parallel* of latitude?

P. Because it is drawn parallel to, and even with, the equator.

T. (Putting his pointer on a place in the southern hemisphere.) What kind of latitude will this place have?

P. South latitude.

T. Here is a meridian passing through a place. Now, if this distance (tracing with his pointer the distance between the place and the equator) be 35°, what is the latitude of the place?

P. 35°.

T. Upon what line, then, is the latitude of a place measured?

P. Upon a meridian line passing through the place.

T. How many things must be given to fix the position of a place upon the earth?

P. Two things: the longitude and latitude.

T. Is this parallel of latitude a great or small circle?

PROBLEMS ON LONGITUDE.

Teacher. When it is noon at Greenwich, what time will it be to a place having 45° west longitude? *Ans.* Nine o'clock in the morning.

T. When it is noon at Greenwich, what time will it be to a place having 60° east longitude? *Ans.* Four o'clock in the afternoon.

T. When it is noon with us, what time will it be to all places on our opposite meridian? *Ans.* It will be midnight.

T. In what time will the earth turn round 1°? *Ans.* 4 minutes.

Because, time in moving round 360° = 24 hours;

$$\text{"} \qquad \text{"} \qquad 1° = \frac{24 \times 60}{360} \text{ min.} = 4 \text{ min.}$$

T. When it is noon at Greenwich, what time will it be to a place having 40° east longitude?

It has been shown in the last question that places having a difference

of 1° of longitude will have a difference of four minutes in time; therefore, a difference of 40° in longitude will have a difference of time equal to forty times four minutes, or two hours and forty minutes. But as the place has east longitude, it will have its noon before us, and consequently, when it is noon with us, it will be two hours forty minutes past noon at the place.

T. The captain of a ship finds that the pointer of his clock, keeping Greenwich time, is at four o'clock in the afternoon when the sun is in the meridian of the place of observation; what is the longitude of the ship? *Ans.* 60° west longitude..

T. If the pointer of the clock, in the last example, be at seven o'clock before noon, what will then be the longitude? *Ans.* 75° east longitude.

THE TROPICS AND ECLIPTIC. — THE ZONES.

Teacher. (Moving his pointer on the tropic of Cancer.) What is this line called?

Pupil. The tropic of Cancer.

T. When does the sun shine perpendicularly over this line?

P. On our midsummer day, or the 21st of June.

T. (Moving his pointer on the arctic circle.) What is this line called?

P. The arctic circle.

T. What places this line upon the globe?

P. The fact that, on our midsummer day, the sun's light extends 23½° over the north pole.

T. (Moving his pointer on the tropic of Capricorn.) What is this line called? And why is it placed here?

P. The tropic of Capricorn. The sun shines perpendicularly over it on our midwinter day, or the 21st of December.

T. (Tracing out the torrid zone.) What zone is this?

P. The torrid zone.

T. By what lines is it bounded?

P. It is bounded by the tropics of Cancer and Capricorn.

T. (Tracing out the temperate zone.) What zone is this, and how is it bounded?

P. It is the temperate zone, and it is bounded by the tropic of Cancer and the arctic circle.

T. How many zones are there, and what are they called?

P. There are five zones: the torrid, the two temperate, and the two frigid zones.

ANNUAL MOTION OF THE EARTH. — CAUSE OF THE SEASONS.

Teacher. (Moving the globe round the candle, &c.) How many motions has this globe?

Pupil. It has two motions: one on its axis, and the other round the candle, which we suppose to represent the sun.

T. What are these two motions of the earth called?

P. The one is called the diurnal motion, and the other the annual motion.

T. Where is the *orbit* of this globe?

P. That line or path in which it is moving round the candle.

T. (Bringing the globe to the position *c*. See Fig. 14, p. 374.) Now, when the earth is in this position, what season have we?

P. Summer, because the sun shines more over the northern than over the southern hemisphere.

T. (Holding a pointer from the candle to the tropic of Cancer *c*.) To what point on the earth's surface would the sun be now shining perpendicularly?

P. To a point in the tropic of Cancer.

T. How much on every side of this point will the sun's light extend?

P. It will extend 90° over the earth on every side, because the sun enlightens one half the earth at one time.

T. How far over the north pole will his light, therefore, at this time extend?

P. As much over the north pole as the tropic of Cancer is from the equator, that is, 23½°.

And so on to the positions *d*, *t*, and *b*.

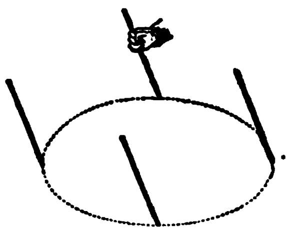


Fig. 33. Parallelism.

Teacher. (Moving a rod without changing its direction.) What have you to say with regard to the position of this rod?

Pupil. That although it is being moved in a circle, yet it still maintains its *parallelism.*

T. Just in the same way, you might say, as the earth preserves the parallelism of its axis while it revolves round the sun. What do you mean by the parallelism of the earth's axis?

P. That it is always parallel to itself, or that it constantly lies in the same direction.

T. (Moving the globe round the candle, with the axis vertical.) Why does this position of the axis not account for the seasons?

P. Because the sun would always shine perpendicularly over the equator, and therefore both hemispheres would always enjoy the same amount of light and heat.

T. What things are necessary in order to account for the seasons?

The remainder of the work may be dissected in the same manner.

ON THE USE OF THE GLOBES.

THE TERRESTRIAL GLOBE.

DEFINITIONS AND EXPLANATIONS.

1. A *globe*, or sphere, is a round body, whose surface is every where at the same distance from a point within it called the centre.

A plane passing through the centre of a sphere divides it into two equal parts, called *hemispheres;* and the section, or

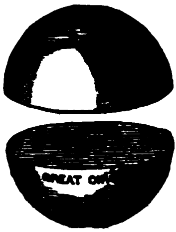


Fig. 1. A Hemisphere.

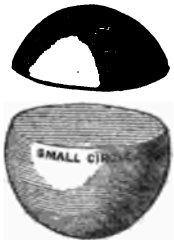


Fig. 2. A Segment of a Sphere.

cut, forms a *great circle* of the sphere. All great circles on the same sphere are obviously equal to one another.

When the sphere is cut by a plane which does not pass through the centre, it is divided into two unequal parts, and the section forms a *small circle* of the sphere. The size of these circles depends upon the distance at which the sphere is cut from the centre.

If a circular hoop be whirled round, it will describe or trace out the surface of a sphere.

Two great circles on a sphere divide each other into equal parts.

These circles cross each other like two equal hoops: thus, the two hoops E Q and C D cross each other at the points A and B, making A C B, A B D, A E B, and A B Q each equal to semicircles. The pole of a great circle on a sphere is every where 90 degrees distant from it.

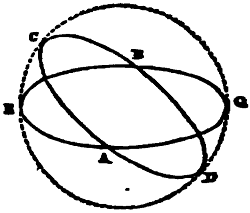


Fig. 3.

2. All circles on the globe are supposed to be divided into 360 equal parts, as in Fig. 4, called degrees. Each quadrant of the circle therefore contains 90 degrees. By means of these degrees the magnitudes of angles are measured: thus, for example, the angle A C K, formed by the two lines A C and C K, contains 40 degrees.

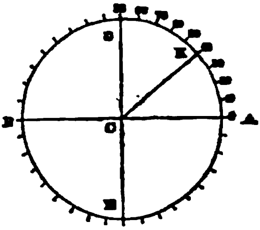


Fig. 4.

3. The *terrestrial globe* is made to represent the earth. Upon the surface of this globe is drawn the outline of the land and water, according to their relative size and situation, together with the various lines and points which have been invented for assigning the exact position of a place upon the earth.

4. The *axis of the earth* is an imaginary line, passing through the centre, upon which the earth turns.

This line is represented, in the artificial globe, by the wire which passes through the north and south poles.

5. The *poles of the earth* are the two extremities of the axis. One pole is called the *north* or *arctic pole,* the other, the *south* or *antarctic pole.*

6. The *equator* is a great circle passing round the globe at equal distances from the poles. It divides the globe into the *northern* and *southern hemispheres.*

The *equinoctial* is the equator referred or extended to the

heavens. When the sun appears in the equinoctial, the days and nights are equal all over the world.

7. *Meridians*, or *lines of longitude*, are semicircles extending between the two poles. These lines cut the equator at right angles.

The meridian passing through Greenwich is called the *first meridian.*

8. The *brazen meridian* is the circle of brass within which the artificial globe turns on two axes representing the poles of the earth. One half of the brass meridian is graduated from the equator to the poles, that is, the point over the equator is marked 0, and the point over the poles is marked 90; this enables us to find the latitude of a place; the other half of the brass meridian commences with 0 at the pole, and ends with 90 at the equator; this enables us to elevate the pole to the latitude of the place.

9. The *longitude of a place* is the distance of the meridian passing through that place from the first meridian, reckoned in degrees on the equator. Longitude is either east or west, according as the place lies to the east or west of the first meridian. The edge of the brazen meridian is usually employed for drawing a meridian through any given place.

10. *Parallels of latitude* are small circles drawn parallel to the equator.

The *polar distance of a place* is its distance from either of the poles.

11. The *latitude of a place* is its distance north or south from the equator, reckoned in degrees on the brass meridian.

12. The *tropics* are two small circles drawn parallel to the equator at the distance of 23½ degrees from it. The tropic in the northern hemisphere is called the *tropic of Cancer*, and that in the southern hemisphere the *tropic of Capricorn.*

13. The *polar circles* are two small circles drawn parallel to the equator at the distance of 23½ degrees from the poles. The north polar circle is called the *arctic circle*, and the south polar one the *antarctic circle.*

14. The *zones*.—The earth is divided by the tropics and polar circles into five parts, called the zones. The portion lying between the tropics of Cancer and Capricorn is called the *torrid zone;* between the tropic of Cancer and the arctic circle, the *north temperate zone;* between the tropic of Capricorn and the antarctic circle, the *south temperate zone;* between the arctic circle and the north pole, the *north frigid zone;* between the antarctic circle and the south pole, the *south frigid zone.*

15. The *ecliptic* is a great circle representing the sun's apparent path throughout the year. It passes through the tropics of Cancer and Capricorn, and is inclined to the equator at an angle of 23½ degrees. The two points where it cuts the equator, or equinoctial, are called the *equinoctial points.*

16. *Signs of the zodiac.*—The ecliptic is divided into 12 equal parts, called the signs of the zodiac; each part therefore contains 30 degrees. There are six northern signs and six southern ones. The sun appears in the former during our spring and summer months, and in the latter during our autumn and winter months. The days on which the sun enters the different signs are as follows:—

Northern Signs of the Zodiac.

Spring Signs.

♈ *Aries*, the Ram, 21st of March.
♉ *Taurus*, the Bull, 19th of April.
♊ *Gemini*, the Twins, 20th of May.

Summer Signs.

♋ *Cancer*, the Crab, 21st of June.
♌ *Leo*, the Lion, 22d of July.
♍ *Virgo*, the Virgin, 22d of August.

Southern Signs of the Zodiac.

Autumnal Signs.

♎ *Libra*, the Balance, 23d of September.
♏ *Scorpio*, the Scorpion, 23d of October.
♐ *Sagittarius*, the Archer, 22d of November.

Winter Signs.

♑ *Capricornus*, the Goat, 21st of December.
♒ *Aquarius*, the Waterman, 20th of January.
♓ *Pisces*, the Fishes, 19th of February.

17. The *equinoctial points* (that is, the two points where the equator cuts the ecliptic) are Aries and Libra. The former point is called the *vernal equinox*, and the latter the *autumnal equinox*. When the sun is in either of these points, the days and nights are equal all over the world.

18. The *solstitial points* are Cancer and Capricorn. When the sun is in or near these points, the variation in the length of the days is scarcely perceptible. When the sun enters Cancer, it is the longest day to all the inhabitants in the northern hemisphere, and the shortest day to those in the southern hemisphere. On the contrary, when the sun enters Capricorn, it is the shortest day to the people who live in the northern hemisphere, and the longest to those who live in the southern hemisphere.

19. The *colures* are two great circles which pass through the poles; one of them, called the *equinoctial colure*, passes through the equinoctial points; the other, called the *solstitial colure*, passes through the solstitial points.

The principal lines on the globe, which have just been described, are represented in the annexed figure; thus N S represents the axis of the earth; N, the north pole; S, the south pole; E Q, the equator; E Q N, the northern hemisphere; E Q S, the southern hemisphere; N *t* S, a meridian; L T, a parallel of latitude; L N, the polar distance of L; *c v*, the tropic of Cancer; *g p*, the tropic of Capricorn; *d e*, the arctic circle; *f q*, the antarctic circle; the surface of the earth lying between *c v* and *g p*, the torrid zone; between *c v* and *d e*, the north temperate zone; between *d e* and the north pole, the north frigid zone; between *g p* and *f q*, the south temperate zone; and between *f q* and the south pole, the south frigid zone; *c p*, the ecliptic; C, one of the equinoctial points; *c* and *p*, the solstitial points; the great circle N C S going round the earth, the equinoctial colure; and N *c* S *v*, the solstitial colure.

20. The *zenith* is that point in the heavens directly over our heads.

North Pole.

South Pole.

Fig. 5.

21. The *nadir* is that point in the heavens which lies directly below our feet.

22. *Antipodes* are those people who live on opposite sides of the earth, and therefore walk feet to feet. Their latitudes, longitudes, days and nights, seasons of the year, are all contrary to each other.

23. The *horizon* is of two kinds: the sensible or visible horizon and the rational or true horizon.

The *sensible* or visible horizon is that circle on the earth which bounds our view.

The *rational* or true horizon is a great circle of the heavens, every where 90 degrees from the zenith. The stars rise and set when they appear on this line.

24. The *altitude* of any object in the heavens is its distance from the horizon. When the body is on the meridian, such as the sun at noon, the altitude is then called the *meridian altitude.*

25. The *zenith distance* of a celestial body is its distance from the zenith.

26. The *quadrant of altitude* is a thin, flexible slip of brass, divided upwards from 0 to 90 degrees, and downwards from

0 to 18 degrees. It admits of being screwed to the brazen meridian. The upper divisions are used for finding the distances between places on the earth, the altitude of the heavenly bodies, &c., and the lower divisions are used for finding the duration of twilight.

27. *Azimuth* or *vertical circles* are great circles passing through the zenith and nadir points, cutting the horizon at right angles. The altitudes of the heavenly bodies are measured on these circles. This is done by screwing the quadrant of altitude on the zenith of the place of observation, and moving the slip of brass until its graduated edge passes through the body.

28. The *azimuth* of any celestial body is an arc of the horizon lying between a vertical circle passing through the body and the north or south points of the horizon.

29. The *amplitude* of any celestial body is the distance at which it rises from the east or sets from the west.

30. The *cardinal points* are the east, west, north, and south points of the horizon.

31. A *mariner's compass* consists of a card, representing the horizon, divided into thirty-two equal parts, called points of the compass, together with a magnetic needle which always turns its north pole *towards* the north. By this valuable instrument seamen direct the course of their ships, and engineers and travellers can at any time ascertain the cardinal points of the horizon.

The needle does not exactly point north and south. In England, at the present time, the north pole of the needle points about 24 degrees to the westward of the north. In laying down a meridian line, an allowance must be made for this variation.

The compass is placed beneath the artificial globe for setting it due north and south.

32. The *wooden horizon*, surrounding the artificial globe, represents the rational horizon. It is usually divided into seven concentric circles: the *first* is for finding the *amplitude* of heavenly bodies. The *second*, for finding their *azimuth*.

The *third* contains the thirty-two points of the *compass.* The *fourth* contains the twelve signs of the *zodiac*, with the degrees of each sign. The *fifth* contains the days of the month, corresponding to every degree of the sun's place in the ecliptic, as indicated in the fourth circle. The *sixth* contains the equation of time, that is, the difference of time between a clock and a sun dial. The *seventh* contains the twelve calendar months.

33. The *hour circle* is a flat ring of brass, turning under the brazen meridian, on the axis or pole of the artificial globe. It is divided into twenty-four equal parts, representing hours. It is used for finding the difference of time between any given places, the length of the day, &c.

34. The *declination* of the sun is his distance, north or south, from the equinoctial. At the equinoxes he has no declination; at the tropic of Cancer he has attained his greatest northern declination; and at the tropic of Capricorn he has attained his greatest southern declination.

35. The *right ascension* of the sun is the distance of the meridian, passing through the sun's place in the ecliptic, from the equinoctial point Aries, reckoned in degrees eastward on the equator or equinoctial.

36. A *right sphere* is that position of the earth where the poles are in the horizon, and the equator passes through the zenith and nadir. The people who live at the equator have this position of the sphere.

37. A *parallel sphere* is that position of the earth where the poles are in the zenith and nadir, and the equator coincides with the horizon. If there were any people living at the poles, they would have this position of the sphere.

38. An *oblique sphere* is that position of the earth where the equator cuts the horizon obliquely. All the people on the earth (excepting those that live at the equator and the poles) have this position of the sphere.

PROBLEMS ON THE TERRESTRIAL GLOBE.

PROBLEM I. *To find the latitude and longitude of any given place.*

RULE. Bring the given place to the east edge of the brass meridian: the degree directly over the place is the latitude; and the degree on the equator cut by the brass meridian is the longitude.

The latitude of a place may be north or south, and the longitude east or west.

EXAMPLES.

1. What is the latitude and longitude of Paris?

Answer. 48° 50′ north latitude, and 2° 20′ east longitude.

Required the latitudes and longitudes of the following places:—

2. Rome; 3. South Cape, Spitzbergen; 4. Malta; 5. Cape Horn; 6. Azores.

7. What is the latitude and longitude of the north pole?

8. What is the greatest latitude a place can have?

9. What is the greatest longitude a place can have?

10. What part of the earth is that which has no latitude?

ANSWERS.

(2.) 41° 54′ N. lat., and 12° 27′ E. long.
(3.) 76° 32′ N. lat., and 13° 45′ E. long.
(4.) 35° 53′ N. lat., and 14° 30′ E. long.
(5.) 55° 58′ S. lat., and 67° 11′ W. long.
(6.) 39° N. lat., and 28° W. long.
(7.) 90° N. lat.; (8.) 90°; (9.) 180° east or west longitude; (10.) The equator.

PROBLEM II. *To find any place on the globe, having its latitude and longitude given.*

RULE. Find the given longitude on the equator, and bring it to the brass meridian; find the given latitude on the brass meridian, and the place immediately under will be the place required.

EXAMPLES.

(1.) What place has 20° north latitude, and 76° west longitude?

Answer. The Island of Cuba.

What places have nearly the following latitudes and longitudes?
(2.) 54° N. lat., and 18½° E. long.
(3.) 30° N. lat., and 31° E long.
(4.) 21° S. lat., and 55½° E. long.
(5.) 29° N. lat., and 18° W. long.
(6.) 34° S. lat., and 18° E. long.

Answers. (2.) Dantzic; (3.) Cairo; (4.) Island of Bourbon; (5.) Canary Islands, Palma; (6.) Cape of Good Hope town.

PROBLEM III. *To find all those places which have the same latitude as a given place.*

RULE. Bring the given place to the brass meridian, and find its latitude; turn the globe slowly round, and all places which pass under the observed latitude will be those required.

All places in the same latitude have the same seasons, and the same length of day and night; but, owing to various physical causes, (such as the relative distribution of land and water,) they may not have the same temperature.

EXAMPLES.

1. What places have nearly the same latitude as Constantinople?
Answer. Naples, Pekin, Philadelphia, &c.
What places have nearly the same latitude as the following:
2. London; 3. Alexandria; 4. Rome?
5. What places have nearly the same length of days as Malta?

Answers. (2.) Rotterdam, &c.; (3.) Cummin's Island, China, &c.; (4.) Nova Scotia; (5.) Cape St. Vincent, Portugal, &c.

PROBLEM IV. *To find all those places which have the same longitude as a given place.*

RULE. Bring the given place to the brass meridian; all places under the edge of the brass meridian, from pole to pole, have the same longitude.

The people living in all those places which have the same longitude, have noon and all other hours of the day alike.

EXAMPLES.

1. What places have nearly the same longitude as Madeira?
Answer. Hecla, Teneriffe, Cape Blanco, &c.

2. What inhabitants of the earth have nearly the same time as the people of the Cape of Good Hope?

3. What places have nearly the same longitude as Gibraltar?

Answers. (2.) Dantzic, Stockholm, &c.; (3.) St. David's Head, Wales, &c.

PROBLEM V. *To find the distance between two places.*

RULE. Lay the edge of the quadrant of altitude over the two places, so that the point marked 0 may be over one of them; then the number of degrees over the other place will give the number of degrees that they are apart.

Multiply the number of degrees by 60, and the product will give the geographical miles; or multiply the number of degrees by $69\frac{1}{10}$, and the product will give the distance in English miles.

Or, take the distance between the two places with a thread, apply that distance to the equator, and it will show how many degrees are contained in the distance.

EXAMPLES.

1. What is the distance between London and Madeira?

Answer. About $22\frac{1}{2}°$, or 1350 geographical miles, or about 1554 English miles.

What is the distance between the following places?

2. London and Constantinople.

3. Cape Verd Isles and the Cape of Good Hope.

4. London and Petersburg.

5. What is the distance of Land's End from Jamaica?

6. Suppose a ship to sail from Liverpool to Madras in the following track: from Liverpool to Cape Verd Islands, thence to St. Helena, thence to the Cape, thence to Mauritius, thence to Ceylon, and thence to Madras; how many English miles are there in the voyage?

ANSWERS.

(2.) 1320 geog. miles, and 1535 Eng. miles.

(3.) 3900 geog. miles, and 4491 Eng. miles.

(4.) 1140 geog. miles, and 1312 Eng. miles.

(5.) 3840 geog. miles, and 4421 Eng. miles.

(6.) About 185°, or 11,100 geog. miles, or about 12,783 Eng. miles.

PROBLEM VI. *The hour of the day being given at one place, to find what hour it is at any other place.*

RULE. Bring the place at which the time is given to the brass meridian; set the hour index to the given hour; turn the globe until the other place is brought under the brass meridian, and the index will point to the required time.

Or thus by calculation. Find the difference of longitude between the two places, allow an hour for every 15 degrees, and four minutes of time for every degree, and the time thus obtained will give the difference of time between the two places. If the place at which the time is required lies to the east of the other place, this difference of time must be added to find the time at the place required; but if to the west, it must be subtracted. See ASTRONOMY, Art. 22, and EXERCISES, p. 413.

EXAMPLES.

1. When it is 4 o'clock in the afternoon at London, what time is it at Petersburg?

Answer. Six o'clock in the evening.

Or thus, more accurately, by calculation. The difference of longitude between London and Petersburg is $30° 25'$. Here the 30 degrees exactly give 2 hours difference of time, and to convert the remaining $25'$ into time, we have

$$\text{No. min. of time corresponding to } 25' = \frac{25}{60} \times 4 = \frac{5}{3} = 1\tfrac{2}{3},$$

which, added to the 2 hours, gives 2 hours $1\frac{2}{3}$ min. for the difference of time.

Now, as Petersburg lies to the east of London, the time at the former place will be 2 hours $1\frac{2}{3}$ min. later than it is at London; that is, the time at Petersburg will be $1\frac{2}{3}$ min. past six in the evening.

2. When it is 1 o'clock in the afternoon at Alexandria, what time is it at Philadelphia?

Answer. Seven o'clock in the morning.

Or thus, more accurately, by calculation.

Longitude of Alexandria $= 30° 16'$ east.

Longitude of Philadelphia $= 75° 19'$ west.

Difference of longitude $= 105° 35'$

$$\text{Difference time in hours} = \frac{105}{15} = 7 \text{ hours.}$$

$$\text{Difference time in min.} = \frac{35}{60} \times 4 = \frac{7}{3} = 2\tfrac{1}{3} \text{ min.}$$

Total difference of time $=$ 7 hours $2\frac{1}{3}$ minutes.

Now, as Philadelphia lies to the west of Alexandria, the time of the former place will be 7 hours 2¼ min. earlier than it is at the latter place; hence the time at Philadelphia will be 57¾ min. past 5 in the morning.

3. When it is 4 o'clock in the afternoon at Cape Horn, what time is it at the Island of St. Helena?

4. When it is 10 o'clock in the morning at Nankin, in China, what time is it at Plymouth, England?

ANSWERS.

(3.) 6 min. past 8 o'clock in the evening nearly.
(4.) ¾ past 1 o'clock in the morning nearly.

PROBLEM VII. *Given the difference of time at any two places to find their difference of longitude.*

RULE. Bring the first meridian to the brass meridian; set the hour index at 12 o'clock; turn the globe until the given time is brought under the brass meridian; and the degree of the equator cut by the brass meridian will be the difference of longitude.

Or thus by calculation. Allow 15 degrees difference of longitude for every hour in the difference of time, or 1 degree for every 4 minutes of time.

EXAMPLES.

1. When it is noon at a certain place, it is 8 o'clock in the morning at London; required the longitude of the place.

Answer. 60° east longitude.

Or thus by calculation. Here the difference of time is 4 hours.

Difference longitude $= 4 \times 15 = 60$ degrees.

As the time at London is before that of the place, it follows that it must have 60 degrees east longitude.

2. When it is 10 o'clock in the morning at London, at what places will it be noon?

3. What places will have noon 7 hours 55 min. before London?

ANSWERS.

(2.) To all places having 30° E. long., — Petersburg, &c.
(3.) To all places having 118¾° E. long., — Nankin, &c.

PROBLEM VIII. *To find the length of a degree in any given parallel of latitude.*

RULE. Lay the edge of the quadrant of altitude parallel to the equator between any two meridians, (15 degrees of longitude apart;) then the number of degrees intercepted between them, multiplied by 4, will give the number of geographical miles contained in a degree of the given parallel very nearly. To find the number of English miles, multiply the geographical miles by 69.1 and divide by 60.

EXAMPLES.

1. How many geographical and English miles are there contained in a degree in the latitude of 40°?

Here the distance between two meridians (15 degrees apart) in the parallel of 40°, is $11\frac{1}{2}$ degrees of the equator nearly; hence we have

Length of 15 degrees longitude on parallel 40°

$= 11\frac{1}{2}$ degrees of the equator

$= 11\frac{1}{2} \times 60$ geographical miles;

Length of one degree longitude on parallel 40°

$$= \frac{11\frac{1}{2} \times 60}{15} = 11\frac{1}{2} \times 4 = 46 \text{ geog. miles}$$

$$= \frac{46 \times 69.1}{60} \text{ Eng. miles} = 52.97 \text{ Eng. miles.}$$

How many geographical and English miles are there contained in a degree in the following latitudes?

(2.) 30°; (3.) 51°; (4.) 56°; (5.) 60°.

ANSWERS.

(2.) 51.9 geog. miles, or 59.7 Eng. miles.
(3.) 37.7 geog. miles, or 43.4 Eng. miles.
(4.) 33.5 geog. miles, or 38.5 Eng. miles.
(5.) 30 geog. miles, or $34\frac{1}{2}$ Eng. miles.

PROBLEM IX. *To find the antipodes of a given place.*

RULE. Place the two poles of the globe in the horizon; turn the globe until the given place comes to the eastern part of the horizon; observe the number of degrees that the place is to the north (or south) of the east point of the horizon, and the same number of degrees counted south (or north) from the west point of the horizon will give the antipodes required.

EXAMPLES.

1. Required the antipodes of London.

Answer. Antipodes Island, near the Island of New Zealand.

Required the antipodes of the following places: 2. The Island of Bermudas; 3. Cape Horn; 4. Cape of Good Hope; 5. the Azores.

Answers. (2.) The south-west part of New Holland; (3.) the east of Lake Baikal; (4.) the north of the Sandwich Islands; (5.) east of Cape Howe.

PROBLEM X. *To rectify the globe for a given place.*

RULE. Elevate or raise the corresponding pole as many degrees above the wooden horizon as are equal to the latitude of the place. See ASTRONOMY, Art. 28.

If the globe be now turned round, so as to bring the place to the brass meridian, it will be seen that the place occupies the zenith of the globe; that is to say, the wooden horizon forms the true horizon to the place.

PROBLEM XI. *To find the sun's place in the ecliptic for any given day.*

RULE. Find the month and the mark corresponding to the day of that month in the outer circle of the wooden horizon; then the coincident mark in the circle containing the signs of the zodiac will give the sun's place in the ecliptic, which may then be found upon the globe.

PROBLEM XII. *To find the sun's declination for a given day of a given month, and to find the places to which the sun will be vertical on that day.*

RULE. Find the sun's place in the ecliptic for the given day, (Prob. XI.;) bring that point of the ecliptic to the brass meridian, and the degree directly over it on the brass meridian is the declination north or south. Turn the globe round, and every place which passes under that degree of the brass meridian will have the sun vertical on that day.

The declination of the sun obviously gives the latitude of the places which will have the sun vertical.

The sun can only be vertical to places lying within the torrid zone.

RULE. Lay the edge of the quadrant of altitude parallel to the equator between any two meridians, (15 degrees of longitude apart;) then the number of degrees intercepted between them, multiplied by 4, will give the number of geographical miles contained in a degree of the given parallel very nearly. To find the number of English miles, multiply the geographical miles by 69.1 and divide by 60.

EXAMPLES.

1. How many geographical and English miles are there contained in a degree in the latitude of 40°?

Here the distance between two meridians (15 degrees apart) in the parallel of 40°, is 11½ degrees of the equator nearly; hence we have

Length of 15 degrees longitude on parallel 40°

$= 11\frac{1}{2}$ degrees of the equator

$= 11\frac{1}{2} \times 60$ geographical miles;

Length of one degree longitude on parallel 40°

$$= \frac{11\frac{1}{2} \times 60}{15} = 11\frac{1}{2} \times 4 = 46 \text{ geog. miles}$$

$$= \frac{46 \times 69.1}{60} \text{ Eng. miles} = 52.97 \text{ Eng. miles.}$$

How many geographical and English miles are there contained in a degree in the following latitudes?

(2.) 30°; (3.) 51°; (4.) 56°; (5.) 60°.

ANSWERS.

(2.) 51.9 geog. miles, or 59.7 Eng. miles.
(3.) 37.7 geog. miles, or 43.4 Eng. miles.
(4.) 33.5 geog. miles, or 38.5 Eng. miles.
(5.) 30 geog. miles, or 34½ Eng. miles.

PROBLEM IX. *To find the antipodes of a given place.*

RULE. Place the two poles of the globe in the horizon; turn the globe until the given place comes to the eastern part of the horizon; observe the number of degrees that the place is to the north (or south) of the east point of the horizon, and the same number of degrees counted south (or north) from the west point of the horizon will give the antipodes required.

3. What is the length of the longest day to the inhabitants of Paris? At what distance from the east point of the horizon does the sun rise on this day?

4. Show that the day is always 12 hours long to the people living at the equator. Show that the 21st of June is the longest day to the inhabitants of the northern hemisphere, and that the 21st of December is their shortest day.

Required the length of the shortest day to the inhabitants of the following places: 5. Edinburgh; 6. New York.

Answers. (2.) Rises ¼ before 6, and sets ¼ after 6; amplitude 5° north of the east point; (3.) Length of the day 16 hours, and about 37° north of the east point; (5.) 6½ hours; (6.) 9 hours.

PROBLEM XIV. *To find the sun's meridian altitude at a given place on a given day.*

RULE. Rectify the globe for the latitude of the place; bring the sun's place in the ecliptic for the given day to the brass meridian; count the number of degrees, on the brass meridian, between that place and the horizon for the meridian altitude required.

Or thus. Find the declination of the sun, and add it to the co-latitude of the place when the declination and latitude are of the same name, but subtract it when they are of different names.

EXAMPLES.

1. What is the sun's meridian altitude at London on our midsummer day?

Answer. 62°. This is the greatest elevation of the sun above the horizon of London.

Or thus by calculation. Here the declination and latitude are of the same name. On this day the declination of the sun is 23½° north, and the co-latitude is 90° less by 51½°, or 38½°; hence the meridian altitude $= 38\frac{1}{2}° + 23\frac{1}{2} = 62°$.

2. What is the sun's meridian altitude at London on our midwinter day?

Answer. 15°. This is the least meridian altitude of the sun to the inhabitants of London.

Or thus by calculation. Here the declination and latitude have different names. In this case, therefore, we have the meridian altitude $= 38\frac{1}{2} - 23\frac{1}{2} = 15°$.

3. Required the sun's meridian altitude at Paris on the 1st of August.

4. What is the sun's meridian altitude at London on the 2d of February?

What would be the meridian altitude of the sun on the 21st of June to the following places? 5. The north pole; 6. The arctic circle; 7. The equator.

Answers. (3.) 59° 10′; (4.) 21½°; (5.) 23½°; (6.) 47°; (7.) 66½° or 23½° from the zenith.

PROBLEM XV. *To find the altitude of the sun at any given place and hour; and also his azimuth.*

RULE. Rectify the globe for the latitude of the given place; bring the sun's place to the brass meridian; set the index to XII.; turn the globe till the index points at the given hour; fix the quadrant of altitude on the brass meridian, at the degree of latitude of the given place, and lay its edge over the sun's place; then count the number of degrees on the quadrant between this point and the wooden horizon, and it will give the altitude required.

The distance of the point, where the edge of the quadrant of altitude cuts the wooden horizon, from the north or south points, will give the sun's azimuth.

EXAMPLES.

1. Required the sun's altitude, &c., at 7 o'clock in the morning on the 5th of May to the inhabitants of London.

Answer. Altitude 21½°, and azimuth 90° from the north point of the horizon.

2. Required the sun's altitude and azimuth at 4 o'clock in the afternoon on the 2d of July, to the inhabitants of Petersburg.

3. Required the same as in the last example to the inhabitants of London.

Answers. (2.) 35° altitude, and azimuth 75° from the south point; (3.) 37° altitude, and azimuth 80° from the south point.

PROBLEM XVI. *The hour and day being given at a particular place, to find the place where the sun is then vertical.*

RULE. Find the sun's declination for the given day; (see Prob. XII.;) this gives the latitude of the required place;

bring the given place to the brass meridian; set the index to the given hour; turn the globe till the index points to XII. noon; then all the places under the brass meridian will have noon at the given time, and the place whose latitude is the same as the sun's declination will have the sun vertical.

EXAMPLES.

1. To what place will the sun be nearly vertical on the 5th day of February, when it is 23 minutes past noon at London?

Answer. The Island of St. Helena.

2. To what place will the sun be nearly vertical on the 30th day of April, when it is 34 minutes past 1 o'clock in the afternoon at London?

Answer. To the Island of St. Jago, one of the Cape Verd Isles.

3. When it is 40 minutes past 6 o'clock in the morning at London on the 25th of April, where is the sun vertical?

Answer. Madras.

4. When it is 4 o'clock in the afternoon at London on the 18th of August, where is the sun vertical?

Answer. Barbadoes.

PROBLEM XVII. *A place within the torrid zone being given, to find those two days of the year on which the sun will be vertical to the given place.*

RULE. Bring the given place to the brass meridian, and observe its latitude; turn the globe on its axis, and mark what two points of the ecliptic pass under that latitude; seek those two points of the ecliptic in the circle containing the signs of the zodiac, on the wooden horizon, and opposite to them will be found the days required.

EXAMPLES.

1. On what two days of the year will the sun be vertical to the inhabitants of St. Helena?

Answer. On the 5th day of February, and on the 6th day of November.

2. On what two days of the year will the sun be vertical to the inhabitants of Madras?

Answer. On the 25th day of April, and on the 18th of August.

What places have nearly the following latitudes and longitudes?
(2.) 54° N. lat., and 18½° E. long.
(3.) 30° N. lat., and 31° E long.
(4.) 21° S. lat., and 55½° E. long.
(5.) 29° N. lat., and 18° W. long.
(6.) 34° S. lat., and 18° E. long.

Answers. (2.) Dantzic; (3.) Cairo; (4.) Island of Bourbon; (5.) Canary Islands, Palma; (6.) Cape of Good Hope town.

PROBLEM III. *To find all those places which have the same latitude as a given place.*

RULE. Bring the given place to the brass meridian, and find its latitude; turn the globe slowly round, and all places which pass under the observed latitude will be those required.

All places in the same latitude have the same seasons, and the same length of day and night; but, owing to various physical causes, (such as the relative distribution of land and water,) they may not have the same temperature.

EXAMPLES.

1. What places have nearly the same latitude as Constantinople?
Answer. Naples, Pekin, Philadelphia, &c.
What places have nearly the same latitude as the following:
2. London; 3. Alexandria; 4. Rome?
5. What places have nearly the same length of days as Malta?
Answers. (2.) Rotterdam, &c.; (3.) Cummin's Island, China, &c.; (4.) Nova Scotia; (5.) Cape St. Vincent, Portugal, &c.

PROBLEM IV. *To find all those places which have the same longitude as a given place.*

RULE. Bring the given place to the brass meridian; all places under the edge of the brass meridian, from pole to pole, have the same longitude.

The people living in all those places which have the same longitude, have noon and all other hours of the day alike.

EXAMPLES.

1. What places have nearly the same longitude as Madeira?
Answer. Hecla, Teneriffe, Cape Blanco, &c.

diurnal arc above the horizon will always be equal to that which is below it. The whole of the heavens may be seen at the equator in the course of a day; and in the course of the year all the stars in the heavens may be seen; whereas, at the poles, only one half of the heavens can be seen. On the equinoxes the sun passes directly over the heads of the people at the equator; when the sun is in the northern half of the ecliptic, at noon his aspect is north; and, on the contrary, when the sun is in the southern half of the ecliptic, at noon his aspect is south.

2. *The parallel sphere.* The people at the north pole, if there were any living there, would have this sphere; the north polar star in the heavens would appear exactly over their heads. To place the artificial globe in this position, elevate the north pole 90° above the horizon, or, what is the same thing, make the equinoctial to coincide with the wooden horizon.

At *the poles*, during six months of the year, the sun shines without setting, and during the other six months he never appears above the horizon. On the 21st day of March, when the sun is in the vernal equinox, he will be seen by the people at the north pole (if there were any) to skim along the horizon; and as the sun increases in his northern declination, he will appear, day after day, to rise higher above the horizon, until he attains his greatest northern declination, (23½°,) and then his elevation above the horizon will be 23½°, that is, it will be equal to his declination; after this, he will gradually decrease in his altitude, until he arrives at the autumnal equinox, when he will again appear to skim along the edge of the horizon; so that he will have been six months above the horizon without setting; after this he will totally disappear for six months. But there will be twilight until the sun is 18° below the horizon, — that is, until he has attained 18° south declination. The same thing will take place with respect to the south pole, but with this difference; while the

sun shines upon the north pole, he will be invisible to the supposed people of the south pole, and *vice versâ*.

A spectator at the north pole can only see the stars in the northern hemisphere, or those stars which lie on the north of the equinoctial.

3. *The oblique sphere.* All people living on the earth, excepting those at the equator and poles, have this position of the sphere. In this case, the horizon cuts the equator obliquely. To place the artificial globe in this position, elevate the north or south pole, as the case may be, to the latitude of the place where we may conceive a spectator to be placed. Let us suppose, for example, that the north pole is elevated to the latitude of London.

To the people living at London, for six months of the year, the days are more than twelve hours long, and for the remaining six months, they are less than twelve hours long; that is to say, from the 21st of March to the 22d of September, when the sun is on the northern side of the equinoctial, the days are more than twelve hours long; and, on the contrary, from the 22d of September to the 21st of March, when the sun is on the southern side of the equinoctial, the days are less than twelve hours long. At the vernal equinox (on the 21st of March) the sun shines perpendicularly over the equator, and the days and nights are equal all over the globe; as the sun increases in his northern declination, the days also increase in length; for the diurnal arcs described by the sun are unequally divided by the horizon; when the sun has attained his greatest northern declination, (June 21st.) the days have also attained their greatest length; but they will be at their shortest to the people in the southern hemisphere; after this, the sun's northern declination gradually decreases, and the days also gradually decrease in length; when he arrives at the autumnal equinox, (Sept. 22d,) the days and nights are again equal; after this, the days become shorter and shorter, as the sun's southern declination increases, until he has attained his greatest southern declination, (December

21st,) and then the days will be at their shortest with us, but at their greatest length to the people of the southern hemisphere; after this, our days increase in length, and when the sun again arrives at the vernal equinox, the days and nights are again equal.

The duration of twilight is greater with us than it is at the equator, because the diurnal arc of the sun cuts the horizon obliquely, which causes him to take a longer time to get 18° below the horizon; whereas, at the equator, the sun sinks perpendicularly below the horizon, which tends to shorten the duration of twilight.

The people that live in the northern hemisphere can never see those stars which lie towards the south polar star, and the people in the southern hemisphere can never see those stars which lie towards the north polar star; but, as already observed, a person at the equator may see all the stars in the heavens in the course of the year.

Problem XX. *Any place in the north frigid zone being given, to find how long the sun shines there without setting, and how long he is invisible.*

Rule. Rectify the globe to the latitude of the place; bring the ascending signs of the ecliptic (the signs going before Cancer) to the north point of the horizon, and observe what degree of the ecliptic is cut by that point; find on the wooden horizon the day and month corresponding to that degree; then from that day the sun begins to shine without setting. Now, bring the descending signs (the signs coming after Cancer) to the north point of the horizon, and observe what degree of the ecliptic is cut by that point; find on the wooden horizon, as before, the day and month corresponding to that degree; then, on that day, the sun ceases to shine without setting. By proceeding in the same manner with the southern point of the horizon, we may find the beginning and end of the period during which the sun is invisible.

Example. How long will the sun shine without setting to the inhabitants of the North Cape, in latitude 71½° north?

Answer. The sun begins to shine continually on the 14th of May, and ceases to shine continually on the 30th of July. The longest day is, therefore, 77 days long; that is to say, the sun shines without setting for 77 days. The period during which the sun will be invisible extends from the 16th of November to the 27th of January. The longest night is, therefore, 73 days long; that is to say, the sun is never seen by the inhabitants of this place for the period of 73 days.

PROBLEM XXI. *To find the beginning and end of twilight at a given place on any given day.*

RULE. Rectify the globe for the latitude of the place; bring the sun's place in the ecliptic on the given day to the brass meridian; set the hour circle to XII.; screw the quadrant of altitude upon the brass meridian over the given latitude; turn the globe westward till the sun's place comes to the western edge of the wooden horizon; then the hour circle will show the time of the sun's setting, or the beginning of evening twilight; continue the motion of the globe till the sun's place coincides with 18 degrees on the quadrant of altitude, below the horizon; then the hour circle will show the time at which the evening twilight ends. The duration of twilight is equal to the difference between the time at which it ends and the time at which it begins. The time at which evening twilight ends, subtracted from 12 will give the beginning of morning twilight, which is of the same duration as the evening twilight.

EXAMPLES.

1. Required the duration of twilight at London on the 22d of September.

Answer. The sun sets at 6 o'clock, and twilight ends at 8 o'clock; consequently the duration of twilight is 2 hours.

2. Required the duration of twilight at those places which have the same latitude as Edinburgh, on the 24th of April.

Answer. 3 hours.

3. What is the duration of twilight at London on the 20th of April?

Answer. 2 hours 18 minutes.

PROBLEM XXII. *Given the sun's meridian altitude, and the day of the month, to find the latitude of the place.*

RULE. If the sun was south of the observer when the altitude was taken, bring the sun's place in the ecliptic to the south side of the brass meridian; move the brass meridian till the sun's place is raised above the horizon equal to the given meridian altitude; then the elevation of the north pole will give the latitude of the place. If the sun was north of the observer when the altitude was taken, proceed in the same manner, with this exception, that the sun's place must be brought to the north side of the brass meridian, and the elevation of the south pole will give the latitude of the place.

EXAMPLES.

1. On the 21st of June, the meridian altitude of the sun was observed to be 69½°, and south of the observer; required the latitude of the place.

Answer. 44° north latitude.

2. On the 21st of December the meridian altitude of the sun was observed to be 25°, and south of the observer; required the latitude of the place.

Answer. 41½° north latitude.

3. On the 10th of May the meridian altitude of the sun was observed to be 30°, and north of the observer; required the latitude of the place.

Answer. 42° 25′ south latitude.

PROBLEM XXIII. *To find the angle of position between two given places.*

RULE. If the two places be on the same meridian, they bear north and south from each other, and therefore their angle of position is 0. When the places are not on the same meridian, proceed as follows: rectify the globe to the latitude of one of the places; bring that place to the brass meridian, and screw the quadrant of altitude over it; move the quadrant till its edge falls upon the other place; then the point where the edge of the quadrant cuts the wooden horizon will give the angle of position between the two places, which is estimated in degrees from the north point, or it may be reckoned by the points of the compass.

EXAMPLES.

1. Required the angle of position between London and Madras.

Answer. 90° from the north towards the east.

2. Required the angle of position between London and Jamaica.

Answer. The quadrant of altitude falls upon the west point of the horizon; the angle of position is 90° from the north towards the west.

3. What is the angle of position between Madrid and Philadelphia?

Answer. 65°.

PROBLEM XXIV. *To find all the places to which a lunar eclipse is visible at a given instant.*

RULE. Find (by Prob. XVI.) the place to which the sun is vertical at the given time; bring the place to the brass meridian, and rectify the globe to the latitude of that place; then at all places within 70 degrees of this place an eclipse of the sun *may* be visible, especially if it be a total eclipse. For a lunar eclipse, after proceeding as before, set the hour circle to XII. noon; turn the globe till the hour circle is at XII. midnight; then an eclipse of the moon will be visible to all those places which are above the wooden horizon.

EXAMPLES.

1. There was an eclipse of the sun on the 9th of October, 1847, at 29 minutes past 7 o'clock in the morning, at London; to what places might it be visible?

Answer. To Hindostan, Arabia, &c.

2. An eclipse of the moon took place on the 26th of January, 1842, at 6 o'clock in the afternoon, at London; to what places was it visible?

Answer. Europe, Asia, Australia, and a portion of Africa.

3. An eclipse of the moon took place on the 31st of May, 1844, at 50 minutes past 10 in the evening, at London; to what places was it visible?

Answer. Europe, Africa, and a portion of Asia.

4. An eclipse of the moon will take place on the 7th of January, 1852, at 30 minutes past 6 in the morning, at London; to what places will it be visible?

Answer. Visible at London, &c.

PROBLEM XXV. *To place the terrestrial globe in the sunshine, so that it may represent the actual position of the earth with respect to the sun.*

Rule. Place the globe directly north and south, by means of the mariner's compass usually placed beneath the globe, taking care to bring the north pole of the needle 24 degrees to the west of the north point of the compass, which is the allowance at present for the variation;* bring the place where you are living to the brass meridian, and elevate the pole to its latitude; then the globe, with its various lines, &c., will correspond in every respect with the position of the earth, and the imaginary lines, &c., upon it, with respect to the sun. The point to which the sun is vertical, the illuminated hemisphere, &c., may all be at once determined.

Problem XXVI. *To construct a horizontal dial by the globe for a given latitude.*

Rule. Place the globe, as in the last problem, directly north and south; rectify the globe to the latitude of the place; bring the first meridian to the brass meridian; then observe the points where the hour meridians on the globe cut the horizon, and number these points according to the hours of the day; thus the point of the dial at the brass meridian must be numbered XII., thence XI., X., &c., towards the west for the morning hours, and I., II., &c., for the evening hours. The style of the dial represents the axis of the earth, and must therefore always make, with the plane of the horizon, or the plane of the dial plate, an angle equal to the latitude of the place.

THE CELESTIAL GLOBE.

DEFINITIONS AND EXPLANATIONS.

1. The *celestial globe* is constructed to represent the aspect of the heavens; all the stars are laid down on its surface according to their relative situations; and the various imaginary circles and points upon the terrestrial globe are supposed to

* At London.

be transferred to the celestial one. The rotatory motion of this globe, from east to west, represents the apparent diurnal motion of the sun, moon, and stars, to a spectator supposed to be situated in the centre of the globe.

2. *The latitude and longitude of a star or planet.*—The latitude of a body, on the celestial globe, is its distance from the ecliptic, north or south, measured in degrees on a great circle passing through the body and the pole of the ecliptic; and the longitude is the distance of the point, where the great circle cuts the ecliptic, from the first point of Aries. Latitude and longitude are referred to the ecliptic, on the celestial globe, but on the terrestrial globe they are referred to the equator.

3. *The declination and right ascension of a heavenly body.*—The declination of a body is its distance from the equinoctial, north or south, measured in degrees on a meridian passing through the body; and the right ascension is the distance of the point where this meridian cuts the equinoctial, from the first point of Aries. The right ascension of a body is sometimes expressed in hours, making the usual allowance of one hour of time for 15 degrees of distance.

PROBLEMS ON THE CELESTIAL GLOBE.

PROBLEM I. *To find the right ascension and declination of the sun or of a star.*

RULE. Bring the sun's place, or the given star, to the brass meridian; the degree over it is the declination, and the degree on the equator cut by the brass meridian gives the right ascension.

EXAMPLES.

1. Required the right ascension and declination of Regulus, in the constellation of the Lion.

Answer. Right ascension 150°, declination 12° 47′ north.

Required the right ascension and declination of the following stars:—

2. Capella, in the constellation of Auriga; 3. Dubhe, in the constellation of the Great Bear; 4. Aldebaran, in the constellation of Taurus; 5. Arcturus, in the constellation of Boötes.

Answers. (2.) Right ascension 76°, declination 45° 49′ N.

(3.) Right ascension 163° 15′, declination 62° 36′ N.

(4.) Right ascension 66°, declination 16° 10′ N.

(5.) Right ascension 212°, declination 20° 3′ N.

PROBLEM II. *The right ascension and declination of a heavenly body being given, to find its place on the globe.*

RULE. Bring the given degree of right ascension (or the given time of right ascension) to the brass meridian; then under the given degrees of declination, reckoned on the brass meridian, you will find the place of the body.

EXAMPLES.

1. Required the star whose right ascension is 76° 45′, or 5 hours 7 minutes, and declination 8° 24′ south.

Answer. Rigel, a star of the first magnitude in the constellation of Orion.

What stars have the following right ascensions and declinations?

	Right Ascensions.	Declinations.
2.	261° 30′ or 17 h. 26 m.	52° 25′ N.
3.	6 h. 38 m.	16° 29′ S.
4.	19 h. 43 m.	8° 26′ N.
5.	7 h. 35 m.	28° 26′ N.

Answers. (2.) β, a star of the second magnitude in the constellation of Draco; (3.) Sirius, in the Great Dog; (4.) Altair, in the Eagle; (5.) Pollux, the south twin.

PROBLEM. III. *To find the latitude and longitude of any star.*

RULE. Bring the pole of the ecliptic to the brass meridian; fix the quadrant of altitude over the pole, and move the quadrant till its edge comes over the star; then the degree of the quadrant over the star is the latitude, and the number of degrees between the edge of the quadrant and the first point of Aries is the longitude.

EXAMPLES.

1. What is the latitude and longitude of Aldebaran, in the constellation of Taurus?

Answer. Latitude 5° 28′ S., longitude 2 signs 6° 53′.

2. What is the latitude and longitude of Pollux, in the constellation of Gemini?

Answer. Lat. 6° 30′ N., long. 3 signs 21°.

PROBLEM IV. *The day and hour, and the latitude of the place, being given, to place the celestial globe so as to represent the appearance of the heavens at that place and time.*

RULE. Place the globe north and south, by the mariner's compass; rectify the globe to the latitude of the place; bring the sun's place in the ecliptic to the brass meridian; set the hour circle to XII.; turn the globe till the index of the hour circle points to the given hour of the day; then in this position the stars figured on the globe will exactly correspond with the actual appearance of the stars in the heavens.

PROBLEM V. *The day and hour, and the latitude of the place, being given, to find what stars are rising, setting, and culminating.*

RULE. Rectify the globe for the latitude of the place; bring the sun's place to the brass meridian; put the hour circle to XII.; turn the globe till the hour circle indicates the given hour of the day; then all the stars on the eastern semicircle will be rising, those on the western semicircle will be setting, those under the brass meridian will be culminating, or in their southing, and those stars above the wooden horizon will be visible at the given time and place.

To determine those stars which never set, turn the globe on its axis; then those stars which do not go below the wooden horizon never set at the given place.

EXAMPLES.

1. To find the constellations which are rising, setting, and culminating, on the 20th of January, at 2 o'clock in the morning at London.

Answer. The constellation of Lyra, &c., are rising; Andromeda, &c., are setting; and the Great Bear, &c., are on the meridian.

2. To find the stars which are rising, setting, and culminating, on the 8th of February, at 9 o'clock in the evening at London.

Answer. A star in the Northern Crown is rising; Arcturus, in Boötes, is a little above the horizon; Sirius is on the meridian; Markab, in Pegasus, a little below the western horizon.

PROBLEM VI. *To find the time when any heavenly body will rise, come to the meridian, and set, on a particular day, at any given place.*

RULE. Rectify the globe for the latitude of the place; bring the sun's place in the ecliptic to the brass meridian; set the hour circle to XII.; turn the globe till the given star* comes to the eastern edge of the wooden horizon; then the hour circle will show the time of rising; now turn the globe till the star comes to the brass meridian, and the hour circle will show the time of its culmination or southing; lastly, turn the globe till the star comes to the western edge of the wooden horizon, and the hour circle will show the time of setting.

EXAMPLES.

1. At what time will Arcturus, in the constellation of Boötes, rise, culminate, and set, at London on the 7th of September?

Answer. Arcturus will rise at about a quarter past 7 in the morning, culminate at a quarter past 3 in the afternoon, and set at three quarters past 10 at night.

2. At what time will Aldebaran, in the constellation of Taurus, rise, &c., at Edinburgh on the 26th of November?

Answer. It rises at about half past 4 in the afternoon, &c.

PROBLEM VII. *The day of the month, the latitude of the place, and the altitude of a star being given, to find the hour of the night.*

RULE. Rectify the globe for the latitude of the place; bring the sun's place in the ecliptic to the brass meridian; set

* The place of a planet on the globe must be found by Prob. VIII.

the hour circle to XII.; screw the quadrant of altitude to the zenith, and turn it to that side of the meridian on which the star was observed; move the globe and the quadrant till the star is on the degree of the quadrant equal to the given altitude; then the hour circle will show the hour required.

EXAMPLES.

1. At Rome on the 2d of December, the star Capella, in the constellation of Auriga, was observed to be 42° above the horizon, and west of the meridian; required the hour.

Answer. Five o'clock in the morning.

2. At London on the 29th of December, the star Deneb, in the tail of the Lion, was found to be 40° above the horizon, and east of the meridian; required the hour.

Answer. About a quarter past 2 o'clock in the morning.

PROBLEM VIII. *Given the year and the day, to find the place of a planet on the globe.*

RULE. Bring the sun's place in the ecliptic to the brass meridian; set the hour circle to XII.; find, in the Nautical Almanac, the time when the planet passes the meridian on the given day, and turn the globe till the index of the hour circle points to the hour thus found; find, in the Almanac, the declination of the planet for the same day; then under this declination, found on the brass meridian, is the place of the planet.

EXPERIMENTAL CHEMISTRY.

Section I.

NATURE OF CHEMISTRY. SIMPLE AND COMPOUND BODIES. ATTRACTION. CHEMICAL AFFINITY. NATURE OF ACIDS AND ALKALIES. SOLUTIONS.

NATURE OF CHEMISTRY. SIMPLE AND COMPOUND BODIES.

1. Chemistry is that science which treats of the properties of the simple substances composing the globe, and of the various compounds resulting from their action upon each other. So far as our present knowledge extends, there are sixty-two simple or elementary substances, which, uniting with each other, form the vast variety of substances found in the earth, the air, and the waters of the ocean and rivers. A simple substance, do with it what we may, will not yield any other kind of substance different from itself. Thus iron is considered to be a simple body, because we can only obtain iron from it. A compound body contains two or more simple substances in a state of chemical combination. Nearly all the substances in nature are compounds. Sulphur and iron are simple substances, but they combine and form a compound substance called sulphuret of iron.

Fig. 1.

Experiment. Take some iron filings and mix them intimately with about half their weight of sulphur; put the mixture into a test tube, and apply the flame of a spirit lamp; at the same time close the mouth of the tube with the fore finger, to exclude the air: the iron and sulphur

combine with ignition, forming the compound of sulphuret of iron — a black substance entirely different from either the iron or sulphur.

2. Elementary substances are usually divided into two classes, namely, metallic and non-metallic. The following list comprises some of the most important elementary substances :—

Non-metallic Elements.

Oxygen, Nitrogen, } gases found in the atmosphere;
Hydrogen, Chlorine, Carbon, Sulphur, Phosphorus, Iodine, &c.

Metals.

Potassium, the metal which forms potassa by combining with oxygen;
Sodium, the metal which forms soda;
Calcium, the metal which forms lime;
Magnesium, the metal which forms magnesia;
Iron, Copper, Zinc, Tin, Lead, Manganese, Arsenic, Chromium, Mercury, Silver, Gold, Platinum, &c.

3. There are many substances, which, although they appear simple, are in reality of a compound nature. Thus water is a compound, being made up or composed of oxygen and hydrogen; the air is chiefly a mixture of oxygen and nitrogen; common salt is a compound, containing chlorine and sodium; and so on to other cases.

DIFFERENT KINDS OF ATTRACTION.

4. *Attraction* is one of the distinguishing qualities of material substances. There are various kinds of attraction.

Attraction of gravitation. — A stone falls to the ground in consequence of the earth's attraction, and the planets in the solar system are maintained in their orbits round the sun by the attractive force which he exerts upon them. This is called the attraction of gravitation, and it subsists between bodies at all definite distances from each other.

5. *Magnetic attraction.* — This is familiarly exhibited in the attraction which the poles of a magnet have for soft iron.

6. *Electrical attraction.*

Experiment. If a stick of sealing wax (or a glass tube) be rubbed

sharply with a dry silk handkerchief, the sealing wax will attract small cuttings of light paper. This is called electrical attraction.

7. *Attraction of cohesion.*

Exp. 1. If an apple be cut in two with a sharp knife, the pieces may be put together so as to adhere.

Exp. 2. Take two balls of lead; scrape a clean portion in each; bring the clean parts in contact, and rub the balls together by giving them a circular motion: they stick or cohere together.

Exp. 3. Two polished plates of metal placed together require considerable force to separate them.

The force manifested in these experiments is called the *attraction of cohesion, or adhesion.* The minute particles, or molecules, of which bodies are composed, are held together by the attraction of cohesion subsisting amongst these particles. Bodies are solid, liquid, or aeriform, according as the force of cohesion is modified by heat.

8. *Capillary attraction* is a peculiar form of cohesion.

Exp. 1. Plunge the extremity of a small glass tube in water: the fluid rises within the small bore of the tube.

Exp. 2. Place a piece of lump sugar on a few drops of water: the fluid rises through the fine pores of the sugar.

CHEMICAL ATTRACTION, OR AFFINITY.

9. However intimately the sulphur and iron, in the experiment Art. 1 may be mixed, we can only by this means produce a mechanical mixture of the particles of the two substances; but, after chemical combination, there is no trace left of either the sulphur or the iron. *Chemical affinity* differs, in certain respects, from all other kinds of attraction. It resembles cohesion, inasmuch as it subsists between the particles, of matter and holds them together; but while cohesion takes place between particles of the same sort, affinity is exerted between the particles of different kinds of matter; and while cohesion produces no change in the properties of a substance, affinity is almost invariably attended with a marked change in the appearance and other properties of the substances forming the compound. All chemical changes are

produced by affinity, or chemical attraction. Combination and decomposition are the results of chemical action.

Combination takes place when particles of different kinds of matter unite and form a new substance.

Decomposition takes place when a substance is resolved into the different kinds of matter of which it is composed or made up.

EXPERIMENTS.

1. To a glass of water add a little oil: the oil floats upon the water, but does not combine with it. Water, therefore, has no affinity for oil.

2. Add ammonia; stir the mixture with a glass rod: the oil and the ammonia combine, and form a soapy substance, called a liniment. Oil and ammonia, therefore, have an affinity for each other. This is a case of simple combination.

3. To the soapy compound in the last experiment add a few drops of sulphuric acid, (oil of vitriol;) the ammonia, having a greater affinity for the sulphuric acid, quits the oil, and combines with the acid, forming the sulphate of ammonia: the oil, being set free, again floats upon the surface. This is a case of composition as well as of decomposition: it is therefore an instance of what is called *single elective affinity*.

4. Dissolve some acetate of lead (sugar of lead) in a glass of water; * add a few drops of sulphuric acid: a white compound of sulphuric acid and oxide of lead is precipitated, or falls to the bottom of the glass. This is also a case of single elective affinity.

5. To a solution of acetate of lead, add a few drops of a solution of sulphate of soda, (Glauber salts:) sulphate of lead is precipitated, as in the last experiment, and acetate of soda remains in solution. Here there is a mutual interchange of substances: hence it is called a case of *double elective affinity*.

10. Compositions, as well as decompositions, are continually going on in the processes of art and nature. A piece of chalk, (carbonate of lime,) heated to redness in the fire, gives off a substance called carbonic acid gas, and quick lime is left. When charcoal (the *carbon* obtained from wood) is burned away, the oxygen in the air combines with the carbon or charcoal, and forms carbonic acid gas, which is of course thrown into the air, and is thus apparently lost; but there is no such thing as destruction or annihilation in nature, for substances

* When any substance is dissolved in water, it is called a solution of that substance.

can only change their form of combination. When a piece of lump sugar is dissolved in water, the sugar, although no longer visible, is not destroyed; it has combined with the water, forming a solution of sugar. In like manner, we are able to explain all other changes of form which bodies undergo around us.

11. NATURE OF ACIDS AND ALKALIES.

EXPERIMENTS.

1. Add a few drops of sulphuric acid to a glass of water; taste the diluted acid: it is sour or acid to the taste. Add a little of the *vegetable blue* liquor of red cabbage * to a glass of water; add a little of the diluted sulphuric acid to this blue solution: it is changed to a red color. The same experiment may be performed with any other acid.

Thus *acids are sour to the taste, and change vegetable blue colors to red.*

2. Ammonia, potassa, and soda are the most common and important alkalies. Add drop by drop of a solution of ammonia to the red liquor of the last experiment, until the red color is changed to a greenish blue. Taste the liquid: it is no longer sour or acid. Add now more acid, drop by drop, until the red color is restored; and so on.

Thus *alkalies neutralize the effect of acids, and change the vegetable blues to green.*

Blue slips of paper, stained by litmus,† are commonly used to ascertain when an alkali exactly neutralizes an acid.

3. To liquid ammonia add sulphuric acid, until a slip of blue litmus paper, dipped into the mixture, is about to change its color to red. This is a solution of sulphate of ammonia. Here the sulphuric acid combines with the ammonia, and forms the sulphate of ammonia, the name of the compound being formed so as to indicate its composition. In like manner, carbonic acid united to lime forms the compound of carbonate of lime; and so on to other cases.

In the same manner various other salts may be formed.

4. Take a small bit of phosphorus; set fire to it upon a piece of glass

* This is simply prepared by boiling common red cabbage, cut into small pieces, for a short time, in no more water than is just sufficient to cover them.

† Litmus is a vegetable blue.

or tin placed in the centre of a common plate, and immediately cover it with a large dry glass. The phosphorus, as it burns, combines with the oxygen of the air, and thus forms phosphoric acid, which rises in white flakes within the glass, and finally falls upon the plate like snow. These flakes have a fine acid taste. After the ignition has ceased, pour a little water on the plate: this dissolves the flakes, and a solution of the acid is obtained.

Fig. 2.

This acid, combining with ammonia, forms phosphate of ammonia; with soda, it forms phosphate of soda; with lime it forms phosphate of lime, (which is principally the composition of bones;) and so on.

5. Burn sulphur after the manner described in the last experiment. Here the sulphur, as it burns, combines with the oxygen in the air, and forms sulphurous acid, which rises, in the form of a colorless gas, into the interior of the glass.. Put a violet flower (or a piece of litmus paper) into the glass: the color is discharged. A little water poured into the plate dissolves the gas.

By a peculiar modification of this process sulphuric acid is made, which is a more powerful acid than sulphurous acid, in consequence of containing more oxygen.

SOLUTIONS.

12. When a substance dissolves in water, the substance is said to be soluble, and we obtain a solution of it. The solution of bodies in liquids presents us with the most simple case of chemical attraction. Water readily combines with sugar, common salt, sulphuric acid, alcohol, &c.; and, on the contrary, it shows no tendency to unite with oil, ether, &c. Camphor readily dissolves in alcohol, but it is almost insoluble in water. The process of solution is much accelerated by heat and agitation. In order to obtain a concentrated solution of some substances, the liquid must be boiled in a common oil flask for some time with the substance. Lime is sparingly soluble in water; yet, if a little lime be added to distilled water, a sufficient portion will be dissolved to indicate the presence of lime. Distilled or pure water should be used for making solutions; however, in most cases, clean rain water will do very well.

EXPERIMENTS.

1. Add a small piece of camphor to alcohol or spirits of wine; stir the mixture; the camphor is soon dissolved, and a clear solution of camphor in alcohol is obtained.

Pour a little of this solution into a glass of water; the alcohol unites with the water, and leaves the camphor floating upon the surface.

2. Add a little lime to a bottle of rain or distilled water; shake it up; and, after corking the bottle, set it aside until the particles of lime have settled to the bottom: pour some of the liquid into a glass, and a clear solution of lime is obtained.

3. Dissolve a little carbonate of potassa (pearlash) in a glass of water; a clear solution of the salt is thus obtained; add a few drops of this solution to lime water: it becomes milky, owing to the formation of carbonate of lime. Here the carbonic acid, having a greater affinity for lime than it has for potassa, combines with the lime, and leaves the potassa in solution. The carbonate of lime is said to be precipitated; that is, it falls to the bottom of the glass, owing to its being nearly insoluble.

4. Breathe through a tube into a solution of lime: a milkiness is produced, owing to the formation of carbonate of lime. Here carbonic acid gas is expired from the lungs.

SECTION II.

FAMILIAR EXPERIMENTAL ILLUSTRATIONS OF THE PROPERTIES AND COMPOUNDS OF SOME OF THE MOST IMPORTANT SIMPLE SUBSTANCES.

CARBON. CARBONIC ACID GAS.

13. When wood is burned (as is done by the charcoal burners) in such a manner as to exclude the air, it is converted into wood *charcoal*, which is nearly pure *carbon*. The diamond is perfectly pure carbon in a crystallized form. Combined with other substances, carbon is found in vegetable, animal, and many mineral substances. When charcoal is burned, in the air it forms carbonic acid — a heavy gas, which extinguishes flame, and is destructive to animal life.

EXPERIMENTS.

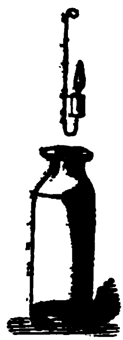


Fig. 8.

1. Put some pieces of chalk (carbonate of lime) into a bottle with a wide mouth; add sulphuric acid (or any other strong acid:) violent effervescence takes place, owing to the escape of carbonic acid gas with the formation of sulphate of lime. Here the sulphuric acid unites with the lime in the chalk, and the carbonic acid in it is set free in the form of gas.

2. In the last experiment the carbonic acid gas, as it is formed, gradually drives out the air in the bottle, and takes its place. This gas, being colorless, cannot be distinguished from common air by the eye: its presence, however, may be detected. Plunge a burning candle into the gas: the flame is instantly extinguished, while the gas remains unchanged.

Thus *carbonic acid gas extinguishes flame, and at the same time it does not take fire*, as some other gases do.

HYDROGEN. COMPOSITION OF WATER.

14. Hydrogen is a colorless, inflammable gas, and the lightest known substance in nature, it being about 14½ times lighter than air. Water is composed of hydrogen and oxygen. Hydrogen also enters into the composition of the inflammable or organic part of plants.

EXPERIMENTS.

1. Put a few pieces of zinc cuttings into the wide-mouthed bottle, (see last fig.;) pour upon them some diluted sulphuric acid; * the mixture soon effervesces, owing to the escape of bubbles of hydrogen gas, which gradually displace the air and fill the bottle. Cover the bottle with a plate, or with a piece of window glass,† to prevent the external air from mingling with the hydrogen. When a sufficient quantity has been obtained, take off the cover, and plunge a lighted candle into the gas: the flame of the candle is extinguished, but the gas takes fire, and burns at the mouth of the bottle, with a pale yellow flame.

* A mixture of 1 part of strong acid to about 4 or 5 parts of water.

† N. B. In all experiments relative to gases generated in this way, it must always be understood that a plate, or a piece of window glass, is to be laid over the mouth of the vessel for a few seconds, in order to exclude the external air.

When hydrogen is mixed with common air, the ignition goes on more rapidly, and sometimes with a slight explosion; but the experiment may be made with perfect safety in the manner just described.

In this experiment, the sulphuric acid, the oxygen portion of the water, and the zinc, combine and form the sulphate of the oxide of zinc; which remains in solution, while the hydrogen portion of the water escapes in the form of a gas.

Thus *hydrogen burns, but does not support flame.*

2. Generate hydrogen in a bottle, as in the last experiment; and, *after the air has been driven out*, close the mouth with a cork, through which the tube of a tobacco pipe passes; light the gas as it issues from the fine opening of the tube. Insert this small flame a few inches into a glass tube, about twenty inches long and one inch in diameter. As the hydrogen burns, it combines with the oxygen of the air; thus water is formed, which covers the interior of the tube in the form of moisture. After a short time, the tube emits musical sounds. These sounds are produced by the air rushing in to fill up the void formed by the ignition of the hydrogen. To show the formation of water, a dry glass may be held over the flame.

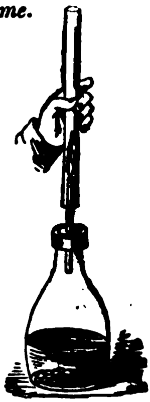


Fig. 4.

OXYGEN AND NITROGEN. THE ATMOSPHERE.

15. The atmosphere is a mixture of oxygen and nitrogen: there is also a small portion of carbonic acid gas *always* present in the air.

EXPERIMENTS.

1. Put a lighted wax candle on the table; place over it a glass jar, previously dried with care; the candle soon begins to burn dimly, as the inflammable substances in it consume the oxygen of the air, and, after a little time, the flame is extinguished; the interior of the glass will now be found covered with drops of water. Here the candle is extinguished, in consequence of the consumption of the oxygen, which, uniting with the hydrogen and carbon of the tallow, forms water and carbonic acid gas. (See also Exp. 4, Art. 11.)

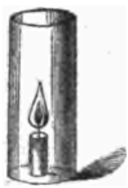


Fig. 5.

2. Put a lighted candle (supported by a bent wire passing through a

Fig. 6.

cork) into a large bottle; close the mouth of the bottle: the flame soon becomes dim, and then goes out, in consequence of the air being no longer able to support combustion. Take out the candle, rekindle it, and plunge it into the bottle: the flame is immediately extinguished.

If a living animal were confined in a close bottle after the oxygen in the air becomes vitiated, the animal would die. A second animal, placed in this vitiated air, would at once expire.

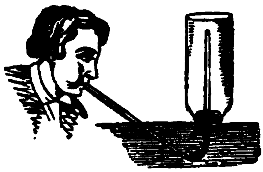


Fig. 7.

3. Take a large bottle containing common air; place its mouth in water; close the nostril with the forefinger and thumb, and inspire and expire the air in the bottle, by means of a bent pewter tube, for a few seconds. At each inspiration, the water rises in the bottle, and at each expiration the water falls. Take the bottle containing the air which has thus been vitiated by passing through the lungs, plunge a lighted taper into it, as in Exp. 2: the flame is extinguished. Here the oxygen of the air is consumed in the act of respiration, and the vitiated air returned to the bottle contains the nitrogen, which was at first in the air, mixed with carbonic acid gas. (See also Exp. 4, Art. 12.)

In the process of breathing, the oxygen taken from the air is returned to it in the form of carbonic acid gas; thus one great end of breathing consists in depriving the blood of its carbon or charcoal.

Thus *oxygen not only supports flame, but also animal life:* hence it is called vital air.

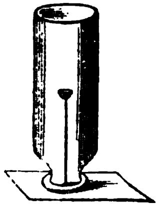


Fig. 8.

4. Place a wire, supporting a small cup, on a stand or shelf covered with water; put a small piece of phosphorus in the cup; ignite the phosphorus, and then invert a large bottle over it. The phosphorus consumes all the oxygen in the bottle, thereby forming phosphoric acid, and leaves the nitrogen. After shaking the water in the bottle, (its mouth being still kept under the water,) the water rises, occupying the place of the oxygen which has been consumed. This will be found to be about $\frac{1}{5}$ of the air at first in the bottle. The residue is nitrogen gas; thus showing that $\frac{1}{5}$ of the bulk of the air is oxygen, and $\frac{4}{5}$ are nitrogen.

5. Take the bottle of nitrogen (covering its mouth with a piece of glass) and place it on the table with its mouth uppermost; plunge a lighted candle into the gas: the flame is extinguished, at the same time the gas does not take fire.

Thus *nitrogen neither supports flame, nor does it take fire as hydrogen does.*

6. Put some green leaves beneath an inverted glass filled with water, and place it in the sunshine: the leaves will be found to give off oxygen gas.

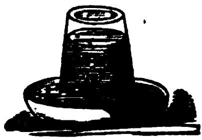


Fig. 9.

Thus *plants give off oxygen gas, while animals consume it.*

7. Introduce some chlorate of potassa in powder (a salt which contains a large quantity of oxygen) into a test tube; apply the flame of a spirit lamp: the salt is decomposed by the heat, all the oxygen gas being given off; apply the finger lightly to the mouth of the tube, to keep the gas as pure as possible; plunge a lighted splinter of wood into the gas; the flame is much increased in brightness; before introduction, blow the flame out so as to have a red spark remaining: the wood is instantly rekindled, thereby showing that pure oxygen is an eminent supporter of combustion.

Fig. 10.

8. Pour some lime water into a glass, and allow it to stand for a few hours: a skin of carbonate of lime is formed upon the surface. This shows that there is carbonic acid gas in the atmosphere.

AMMONIA.

16. This gaseous substance is composed of nitrogen and hydrogen. Water dissolves a large quantity of this gas, and the solution is called liquid ammonia, or hartshorn. It readily combines with all the acids, and forms salts of ammonia. This substance is invariably given off from animal matter in a state of putrefaction; the ammonia thus formed rises into the air, where it floats until it is washed down by the rains to fertilize the soil. It is one of the most fertilizing substances found in farm yard manure and guano.

EXPERIMENTS.

1. Hold test paper over a bottle of liquid ammonia: a powerful alkaline action is exhibited. Smell the ammonia; it has a strong pungent odor.

2. Dip a glass rod in hydrochloric acid, and hold it over a bottle of liquid ammonia: white fumes of hydrochlorate of ammonia are formed.

3. Take a bottle of hydrochloric acid into a horse stable; take out the stopple of the bottle: white fumes, as in the last experiment, are formed about the mouth of the bottle.

4. Take two bottles; put a little liquid ammonia into one of them, turning the bottle round so as to spread the ammonia over the interior; in like manner introduce hydrochloric acid into the other bottle; bring the mouths of the bottles together, as in the annexed cut: the dense white fumes of hydrochlorate of ammonia are produced.

Fig. 11.

5. Take equal parts of hydrochlorate of ammonia (sal ammoniac) and quick lime, each separately powdered, and mix them briskly together; the strong pungent fumes of ammoniacal gas will be felt.

6. Perform the same experiment with a mixture of guano and quick lime: ammonia is in this case given off from the guano.

7. To a solution of carbonate of ammonia add a solution of oxalic acid until effervescence ceases: a solution of oxalate of ammonia is obtained. Here the acid and ammonia combine with the escape of carbonic acid gas.

NITRIC ACID, OR AQUA FORTIS.

17. This important substance is a compound of nitrogen and oxygen. It is manufactured from nitre, (nitrate of potassa,) a substance composed of nitric acid and potassa. There is reason to believe that nitric acid is formed in the air during thunder storms. Decaying organic substances containing nitrogen yield this acid. Nitric acid, as well as ammonia, supply the growing plant with nitrogen.

THE ATMOSPHERE.

18. The *atmosphere* is that vast ocean of elastic fluid which every where surrounds the globe, extending to the height of

about fifty miles above the tops of our highest mountains. This subtle, elastic fluid bears on its tide the exhalations of the earth over every clime, descends to the lowest depths of our mines, and penetrates into the recesses of our darkest caverns. Although invisible to the eye, and although bodies move through it with apparent ease, yet the chemist has weighed it in his balance, and determined its composition with an exactness which challenges dispute. Every where the composition of the air is the same,* — as far as regards its essential elements, — whether it be taken from the confined alleys of our crowded cities, or from the mountain tops over which the healthful winds play with unobstructed freedom. Winds, air in motion, drive our vessels through the ocean, and perform useful labor in our windmills. The atmosphere is the great agent by which heat is nearly equally distributed over the earth, and without its agency light itself would scarcely serve the purposes for which it is designed. By its means moisture is scattered over the vegetable creation in the form of rain and dew; and these rains wash down ammonia, nitric acid, and various exhalations essential to the growth of plants.

The substances *essential* to the constitution of the atmosphere are oxygen, nitrogen, carbonic acid gas, and watery vapor. The oxygen, as we have shown, is necessary to the existence of the animal world, and to the support of combustion; while the nitrogen tends to moderate the intensity of the action of the oxygen. The comparatively small portion of carbonic acid gas in the air affords an important part of the food to the vegetable world, and the watery vapor, besides serving other important purposes, tends to keep the skin of animals and the surface of plants in a moist condition. The beautiful adjustment of the relative proportion of these substances to suit the wants of animals and plants, is a remarka-

* This arises from the diffusiveness of gases, or the tendency which they have to intermix with each other, without regard to their difference of density or heaviness.

ble instance of the nice adaptation of means for the production of a proposed end.

The air is being continually supplied with carbonic acid gas from the respiration of animals; from the burning of wood, coal, and other combustible bodies; and from all animal and vegetable substances in a state of decay. Farm yard manure, also, put into the soil in a fermenting state, yields an abundant supply of carbonic acid gas, as well as of ammonia, to the growing plant. The atmosphere, however, affords the chief source of carbonic acid to plants, which, assimilating the carbon, give off the oxygen into the air, to make up the deficiency produced by the respiration of animals. Guided by an unseen power, one part of creation administers to the necessities of another part: thus plants and animals are necessary to each other's existence, — the one supplies what the other consumes, — what is discharged as useless from the one becomes essential food to the other. This remarkable law of compensation seems to run through the whole of the universe, and a proper appreciation of its nature cannot fail in forcibly impressing upon our minds the great and solemn fact — that the universe is the work of a Being infinite in wisdom, goodness, and truth.

Thus the atmosphere, which appears as nothing to the vulgar eye, is not less essential to the economy of nature, than the solid matter of which the globe is composed, or the great ocean of waters which float upon its surface.

EXPERIMENTS, WITH DESCRIPTIONS OF PNEUMATIC APPARATUS.

1. Draw water into the mouth by a tube. Here the process of sucking draws the air from the tube, and the pressure of the external air causes the water to rise in the tube. The pipette, used in many chemical experiments, depends on this principle. When the finger is placed upon the upper opening, C, the fluid in the tube remains suspended; and, on the contrary, when the finger is removed, the fluid descends drop by drop from the small orifice O of the lower extremity. (For a complete account of the various mechanical properties of the atmosphere, see the Treatise on Pneumatics.)

Fig. 12.

2. Invert a bottle F, filled with water, in the same fluid; the water remains suspended in the bottle by the pressure of the external air. Blow through a tube *g s t* into the mouth of the bottle; the air rises in bubbles through the water and displaces it.

This explains the principle upon which the *pneumatic trough* depends. This simple piece of chemical apparatus is used for receiving different

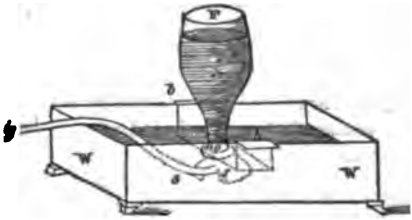


Fig. 13.

kinds of gasses in bottles and gas receivers: it consists of a rectangular trough W W, with the shelf *b b*, having a funnel-shaped hole passing through it, for placing the bottles and receivers on; when it is about to be used, water is poured into the trough, so as to cover the shelf to the depth of about an inch; the mouth of the bottle intended to receive the gas is placed over the hole in the shelf, and the beak of the retort, in which the gas is being formed, is placed immediately below this orifice: the gas then rises in the bottle and displaces the water.

In the annexed cut, *r* is the retort, containing the mixture from which

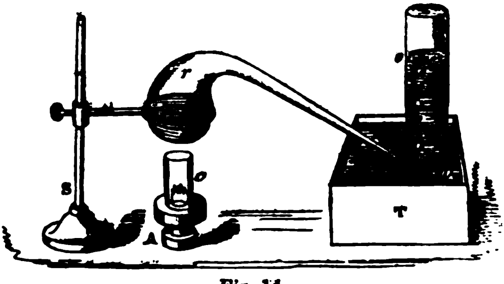


Fig. 14.

the gas is to be made, with its beak placed below the hole in the shelf *w*; T the pneumatic trough filled with water; *e* the gas receiver; S the

retort stand, with its ring supporting the retort *r*; A an *Argand lamp*, with its chimney *c*, for applying a steady heat to the retort when it is required for generating the gas: some gases, however, such as hydrogen, for example, are given off from the materials in the retort without the aid of external heat.

N. B. In the preparation of gases in this way, it should be observed that the gas which first comes over is mixed with the atmospheric air in the retort; hence a volume of gas equal to about twice the volume of the retort should be thrown away as impure; this should especially be attended to in the case of gases (such as hydrogen) which detonate when mixed with atmospheric air.

Gases may be transferred from one vessel to another, over the pneumatic trough. In order to transfer the gas from *e* to *b*, bring the lower edge of *e* to the mouth of *b*; gradually depress the upper end of *e*; bubbles of gas will pass from *e* and fill the vessel *b*.

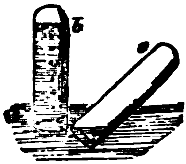


Fig. 15.

When a large quantity of gas is to be made, the *gas holder* is preferable to the pneumatic trough. This valuable piece of apparatus consists of a closed cylindrical vessel A, and a shelf B, open at the top, supported on three rods; *a c* is a pipe, open at each extremity, reaching from the bottom of the shelf to the bottom of the cylinder; *e b* is another pipe which merely enters the top of the cylinder; communications can be opened by the cocks *a b*; *d* is a cock through which the gas in the cylinder may be drawn off; *h* is an aperture for introducing the pipe which conducts the gas into the receiver A; *f g* is a glass tube opening into the cylinder at the top and bottom, to show the quantity of gas that may be in the cylinder at any time. To fill the cylinder A with gas: A is first filled with water, which is done by opening the three cocks *a*, *b*, *d*, closing the aperture *h* with a cork, and pouring water into the shelf B: the water runs through the pipes *a* and *b* into A, expelling the air through *d*. When A is filled with water, the cocks *a*, *b*, and *d* are closed, and the aperture *h* is opened; the water remains in the cylinder A in consequence of the atmospheric pressure, just in the same way as water is suspended in

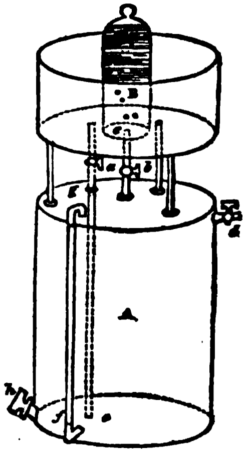


Fig. 16.

the bird fountain; introduce the tube proceeding from the retort into the aperture *h*; the gas will then rise in bubbles into the cylinder, displacing the water through *h*. To fill a jar B with the gas: Pour water on the shelf B; open the cocks *b* and *a*; the gas then rises in bubbles into B, from the pressure produced by the column of water in the pipe *a c*. The gas may also be transferred through the cock *d*.

SULPHUR.

19. This important elementary substance abounds, in its simple state, in the Island of Sicily, and in many volcanic countries. It is also found in combination with iron and copper, in many parts of the world. Sulphuric acid is the most important compound of sulphur; united with various bases, such as lime, soda, magnesia, &c., it forms sulphates, which are found abundantly in the mineral kingdom.

EXPERIMENTS.

1. Heat sulphur in a test tube; the sulphur first melts, and then rises in vapor, which condenses in the cold part of the tube. (See also Exp. 1, Art. 1, and Exp. 5, Art. 11.)

2. To a solution of baryta add sulphuric acid; the white precipitate of sulphate of baryta falls, which is not dissolved by nitric acid. This is the best test for the presence of sulphuric acid.

3. Put some sulphuret of iron in a bottle, and pour some diluted sulphuric acid upon it; sulphuretted hydrogen gas is given off, which has the smell of rotten eggs; dip a slip of white paper in a solution of acetate of lead, and suspend the paper in the bottle containing the gas: the paper is rendered black from the formation of the sulphuret of lead.

Sulphuretted hydrogen, or *hydrosulphuric acid*, is highly inflammable, and is much used as a test for the presence of different kinds of metals. The fumes of this gas should be avoided, as it is deleterious to animal life.*

PHOSPHORUS.

20. This elementary substance is very inflammable, and therefore should be handled with great caution. It has very

* All fumes given off by chemical action should be carefully avoided.

much the appearance and consistence of wax. Phosphorus is now universally prepared from bones.

EXPERIMENTS.

1. Fold a thin slice of dried phosphorus in a piece of paper; rub it briskly with any smooth body: the heat produced by the friction speedily ignites the phosphorus.

2. Write upon the wall with a stick of phosphorus, (wrapped round with a piece of paper;) the writing appears luminous in the dark. (See also Exp. 4, Art. 11.)

3. *Phosphuretted hydrogen gas.* — Put some zinc cuttings and a few small slices of phosphorus into a glass tumbler; take the glass into a dark room, and add some diluted sulphuric acid: the mixture appears like *a well of fire*, in consequence of the escape of phosphuretted hydrogen gas, which ignites spontaneously when it comes into the air.

IODINE.

21. This elementary substance is solid, having a dark bluish color, with a somewhat metallic lustre. It is found in sea water and marine plants. It is highly soluble in alcohol, but is sparingly dissolved by water. Its most important compound is iodide of potassium, which is now much used as a medicine.

EXPERIMENTS.

1. Heat one or two grains of iodine in a flask: the beautiful violet vapor of iodine rises within the flask, and slowly condenses.

2. Dissolve a *very small* piece of iodine in water: the water has a brown color. To this solution add a *cold* solution of starch:* the beautiful blue compound of iodide of starch is formed.

3. Drop a small piece of iodine on a few grains of phosphorus: the substances combine with ignition.

4. To a *cold* solution of starch add a few drops of iodide of potassium; no action is produced: add now a little sulphuric acid to set the iodine free; the blue iodide of starch is formed.

* Starch should be dissolved in hot water.

CHLORINE.

22. Chlorine is a greenish-yellow gas, (hence its name,) which has a pungent, suffocating odor; it is not inflammable, but it supports combustion; indeed, some bodies ignite in it spontaneously. It combines with the metals, forming chlorides; thus common salt is a chloride of sodium. With oxygen it forms acids; the most important of these is chloric acid, which, combined with potassa, forms chlorate of potassa, a salt largely employed in the manufacture of lucifer matches. Chlorine destroys all coloring matters and offensive effluvia.

Experiments.

1. Put a table spoonful of chloride of lime (common bleaching powder) into a bottle; add an equal bulk of hydrochloric acid; chlorine, in the form of a greenish-yellow gas, soon fills the bottle: introduce a lighted candle; it burns with a dull red-colored flame in the gas; suspend a moistened slip of blue litmus paper (or any other colored substance) in the gas: the paper is soon bleached by the gas.

2. To a mixture of common salt and black oxide of manganese add sulphuric acid; chlorine gas is given off. This is a highly convenient way of using chlorine for purposes of fumigation. The chlorine destroys all noxious malaria.

3. Add hydrochloric acid so as to cover half a tea spoonful of chlorate of potassa in powder, in a small bottle; chlorine gas (mixed with chlorous acid) is generated; dip a slip of writing paper into oil of turpentine, and introduce it into the gas: combustion immediately takes place. Perform the bleaching experiment described in Exp. 1.

Chlorous acid explodes with great violence, when heated even to a moderate temperature.

4. Mix a few grains of powdered lump sugar with twice the quantity of chlorate of potassa; let fall a drop of sulphuric acid on the mixture: chlorous acid is disengaged, which immediately inflames the mixture.

5. Carefully fold in a piece of paper a little chlorate of potassa in powder, with a small piece of phosphorus; strike the mixture with a hammer: a loud explosion takes place.

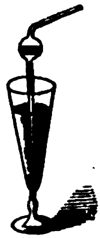


Fig. 17.

6. *To inflame phosphorus under water.*—Put some crystals of chlorate of potassa, together with a few slices of phosphorus, into an ale glass; fill the glass with cold water; let

fall a few drops of sulphuric acid, by means of a pipette, on the chlorate of potassa: the acid takes up the potassa from the salt, and sets free a compound of chlorine and oxygen, which inflames the phosphorus.

HYDROCHLORIC ACID.

23. Hydrochloric acid, or muriatic acid, is a gas, composed of hydrogen and chlorine; it is largely dissolved by water, forming common aqueous hydrochloric acid.

Experiment.

Add diluted sulphuric acid to common salt, in a bottle; hydrochloric acid gas is given off with effervescence, and fills the bottle; suspend a slip of moist blue litmus paper in the gas: the color is changed to red; plunge a lighted candle into the gas: the flame is extinguished.

In this experiment the acid decomposes the salt, which is a compound of chlorine, sodium, and water; the hydrogen of the water unites with the chlorine, and forms hydrochloric acid gas; and the oxygen of the water unites with the sodium, and forms soda, which combines with the sulphuric acid, and forms the sulphate of soda.

Section III.

METALS AND METALLIC OXIDES.

POTASSA AND SODA.

24. Potassium and sodium, united with oxygen, form potassa and soda. These important substances are called *fixed alkalies*, to distinguish them from ammonia, which is called the volatile alkali. (See Art. 11.) Potassa is found in the ashes of plants, and soda in the salt of sea water.

Experiments.

1. Throw a grain of potassium upon water; it floats on the water, and takes fire: a solution of potassa is formed by the union of the oxygen of the water with the metal.

2. Burn some pieces of wood; collect the ashes, and pour water upon them to dissolve the potassa which is in them; add a solution of some vegetable blue: the color is changed to green.

3. Boil, in an iron vessel, equal weights of slaked lime and carbonate of potassa (pearl ashes) in about twelve times the weight of water; the carbonic acid unites with the lime, forming the insoluble carbonate of lime, leaving the potassa in solution. Cover the mixture, and allow it to stand until the carbonate of lime subsides; draw the clear solution off by means of a siphon.* When a solution of potassa is exposed to the air, it speedily takes up carbonic acid, and returns to the state of carbonate of potassa.

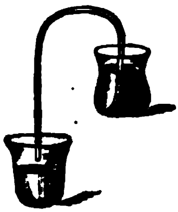


Fig. 18.

4. To a strong solution of carbonate of potassa add a solution of tartaric acid; crystals of bitartrate of potassa (cream of tartar) are formed with the escape of carbonic acid gas.

5. Boil nitrate of potassa (nitre) in water, so long as any of the salt is taken up; decant the solution, and as it cools, crystals of nitre, in six-sided prisms, are deposited.

Soda is found in the ashes of sea weed; it is also obtained from common salt. The compounds of soda are very similar to those of potassa.

LIME.

25. Chalk, limestone, marble, lime shell, and calcareous spar, are all compounds of lime and carbonic acid. Lime

* Insoluble substances, or precipitates, are usually separated from liquids by FILTRATION, which consists in passing the liquid through *filtering paper* placed in a funnel *f*; by this process the clear liquid drops into the glass *g*, and the precipitate or insoluble substance remains on the filtering paper.

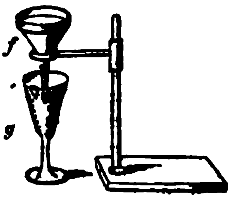


Fig. 19.

These filters are formed by making two folds, in a round piece of paper, at right angles to each other, and in a contrary direction; when this piece of paper is placed within the funnel, it will assume the form of *p*, shown in the cut. The liquid to be filtered should be carefully poured upon *the sides* of the filter, so as not to injure the paper at the bottom part. Before use, the filter paper should be moistened with distilled water.

Fig. 20.

forms an essential constituent of all good soils. Mixed with vegetable or animal substances, it promotes their decay, and at the same time absorbs the noxious gases that are given off. Lime is an oxide of a metal called calcium.

Experiments

1. Expose lime water, in an open vessel, to the air; a crust of carbonate of lime soon appears upon the surface. See also Experiments 2, 3, and 4, Art. 12.

2. Pour hydrochloric acid upon some pieces of chalk, so long as any effervescence is seen: a solution of hydrochlorate of lime is formed.

3. Make a solution of nitrate of lime, by adding nitric acid to chalk, after the manner of the last experiment.

4. Pour a little of the solution of hydrochlorate of lime into an ale glass, and about the same quantity of strong sulphuric acid into another glass; pour the latter quickly upon the former; a violent effervescence takes place from the escape of hydrochloric acid: a solid white substance, sulphate of lime, is formed. Owing to the condensation, great heat is evolved.

5. To any solution of lime add oxalate of ammonia; (see Exp. 7, Art. 16:) the white insoluble oxalate of lime falls.

MAGNESIA.

26. This substance is found in sea water, in certain varieties of limestone, (magnesian limestone,) and in many spring waters. Magnesia is the oxide of a metal called magnesium.

Experiments.

1. To diluted sulphuric acid add carbonate of magnesia (a white powder) until effervescence ceases: a solution of sulphate of magnesia (Epsom salts) is obtained.

Boil off or evaporate a portion of the water; * set aside the solution until it cools: crystals of the salt will be formed.

2. To a solution of sulphate of magnesia add a solution of carbonate of potassa: a white precipitate of carbonate of magnesia is formed.

* Evaporations are best conducted in porcelain dishes, or, as they are called, evaporating dishes; the heat should be applied by a sand bath, or by an Argand lamp with a tin or copper chimney.

This distinguishes Epsom salts from oxalic acid, a poison frequently mistaken for the former. It is further to be observed, that oxalic acid is sour to the taste, whereas Epsom salts are bitter. Oxalic acid is dissipated when thrown upon hot cinders, whereas Epsom salts leave a white mass behind.

ALUMINA.

27. This earth is an oxide of a metal called aluminum; it abounds in common clay. It is distinguished by its insolubility, and by being dissolved in a solution of potassa. Alum is one of its most useful and common compounds. This salt contains alumina, potassa, and sulphuric acid. Pure clay is a compound of silica and alumina, in the proportion of about 3 parts of the former to 2 of the latter.

Experiments.

1. Add ammonia to a solution of alum: alumina falls in consequence of the ammonia combining with a portion of the acid.
2. Perform the same experiment, using potassa or soda.
3. In a saturated solution of alum suspend a basket formed of woollen thread: the alum forms beautiful crystals on the thread, thereby forming *an alum basket.*

SILICA.

28. This earth, like alumina, is very abundant in nature. Quartz is nearly pure silica, and it is the chief ingredient in sand and common flint. Mixed with clay, it forms the great body of soils. Silica is an oxide of silicon.

Experiments.

1. Mix one part of fine sand with three parts of carbonate of potassa; fuse the mixture in a crucible; carbonic acid is driven off, and the silica and potassa combine and form a glass, called silicated potassa, which readily dissolves in water; pour out the silicated potassa on an iron plate; dissolve a portion of it in water. This experiment is highly important, considered in relation to agricultural science.
2. To the solution of silicated potassa add a solution of hydrochlorate of ammonia; the hydrochloric acid combines with the potassa, and the silica is precipitated.

IRON.

29. This valuable metal is found in a great variety of forms in nature. Combined with oxygen, it is found as an oxide of iron; with sulphur, as a sulphuret of iron; with carbonic acid, as a carbonate of iron.

EXPERIMENTS.

1. Place some iron filings in a saucer; moisten them from day to day, until they become *rust*, or oxide of iron, by combining with oxygen.

2. To some iron filings add diluted sulphuric acid: hydrogen gas is given off, and a solution of iron (green vitriol) is formed. Here the oxygen of the water combines with the iron, forming oxide of iron, which unites with the acid, forming the sulphate of the oxide of iron, or, as it is simply called, sulphate of iron.

Decant the clear solution, evaporate it, and set it aside; when the solution is cold, green crystals will appear.

3. Add a few drops of a strong solution of sulphate of iron to four glasses containing water:—

i. To the first add a solution of potassa: oxide of iron falls.

ii. To the second add a solution of carbonate of potassa: carbonate of iron falls.

iii. To the third add a solution of prussiate of potassa: a fine blue precipitate of Prussian blue is formed.

In these three experiments, the sulphuric acid combines with the potassa, and remains in solution.

iv. To the fourth, add an infusion of galls: the black gallate of iron, the substance which gives the color to ink, after a few seconds appears.

4. To a glass of water add a few drops of ink; add oxalic or hydrochloric acid: the color disappears.

5. Write on paper with a very diluted solution of sulphate of iron; when dry, the writing is invisible; wash it over with a solution of prussiate of potassa: the writing appears of a fine blue color.

COPPER.

30. This metal exists in nature in its pure or metallic state; but it is chiefly found as a sulphuret of copper, (copper pyrites.)

EXPERIMENTS.

1. Heat copper for some time in the fire; suddenly plunge the heated copper into water: the oxide of copper is formed in scales on the surface of the metal.

2. Put some slips of copper into diluted nitric acid, which is colorless: a portion of the copper is soon dissolved by the nitric acid, and a fine blue solution of nitrate of copper is formed. Here a portion of the acid gives up oxygen to the metal, forming oxide of copper, which combines with the nitric acid. Red fumes of nitrous acid are given off.

By evaporation, this salt may be obtained in crystals.

3. Into a solution of sulphate of copper (blue vitriol) dip a clean piece of iron: the plate is covered with metallic copper. Here the copper is precipitated in consequence of the iron uniting with the acid to form sulphate of iron.

4. Add two drops of a strong solution of sulphate of copper to two glasses containing water: these solutions will be nearly colorless.

I. To the first add a drop of ammonia; light blue oxide of copper falls: add ammonia now in excess; the precipitate is redissolved, and the solution assumes a fine deep-blue color. This is a very delicate test of the presence of copper.

II. To the second add carbonate of potassa: light blue carbonate of copper falls.

5. Place a few crystals of nitrate of copper on a piece of tin foil; add a few drops of water to the crystals, and quickly fold up the tin foil round them: a violent chemical action takes place, and the tin foil inflames.

LEAD.

31. The most common native form of lead is sulphuret of lead, or galena.

EXPERIMENTS.

1. Heat lead in an iron spoon: it soon melts, and then oxidates, by taking oxygen from the air.

2. Arrange seven glasses, each containing a diluted solution of acetate of lead, (sugar of lead.)

I. To the first add an alkali: the oxide of lead falls.

II. To the second add carbonate of potassa: the white carbonate of lead (white lead) falls.

III. To the third add sulphuric acid, or any sulphate: white sulphate of lead falls.

40*

IV. To the fourth add hydrochloric acid: white chloride of lead falls.

V. To the fifth add a few drops of a solution of iodide of potassium: the beautiful yellow iodide of lead falls.

VI. To the sixth add a few drops of the solution of chromate of potassa: yellow chromate of lead falls.

VII. To the seventh add hydrosulphuret of ammonia: the black sulphuret of lead falls. (See Exp. 4, Art. 60.)

3. Suspend a piece of zinc in a moderately strong solution of acetate of lead: the lead appears deposited on the zinc in an arborescent form, producing what is called the *lead tree*. Here the zinc takes the place of the lead, and the latter is precipitated.

CHROME.

32. The most common salt of this metal is bichromate of potassa.

EXPERIMENTS.

Arrange four glasses, each containing a diluted solution of bichromate of potassa.

1. To the first add carbonate of potassa: it unites with the excess of acid, and yellow chromate of potassa appears.

2. To the second add acetate of lead. (See Exp. 2, Art. 31.)

3. To the third add a few drops of the nitrate of mercury: the orange-colored chromate of mercury falls.

4. To the fourth add a few drops of the nitrate of silver, (lunar caustic:) brick-red chromate of silver falls.

MERCURY.

33. This metal is sometimes found native in the metallic form, but it is most commonly combined with sulphur. This metal is a fluid.

EXPERIMENTS.

1. Heat a few grains of mercury in a test tube over the spirit lamp: the mercury rises in vapor, and condenses in globules in the cold part of the tube.

2. Heat a little sulphur, with about five times its weight of mercury, in a test tube: close the mouth of the tube lightly with the forefinger: vermilion, or bisulphuret of mercury, is formed.

3. To a solution of chloride of mercury (corrosive sublimate) add a few drops of iodide of potassium: a red biniodide of mercury falls.

4. Heat some mercury with nitric acid; the mercury takes oxygen from a portion of the acid, and combines with the other portion; and a solution of nitrate of mercury is formed.

ZINC.

34. This metal is now much used for making water pipes and spouts.

EXPERIMENTS.

1. Take the solution of sulphate of zinc obtained by Exp. 1, Art. 14; evaporate a portion of the water off; set the liquid aside to cool: prismatic crystals of sulphate of zinc fall.

2. To a solution of sulphate of zinc add a few drops of ammonia, (or potassa:) white oxide of zinc falls. Add ammonia in excess: the precipitate is completely redissolved.

3. To a solution of zinc add a few drops of the carbonate of ammonia: carbonate of zinc falls, which is redissolved by an excess of the precipitant. These two experiments form the tests for the presence of zinc.

SILVER.

35. Silver is distinguished by its brilliant lustre and fine white color.

EXPERIMENTS.

1. To a few small pieces of silver add diluted nitric acid; apply heat until the acid ceases to give off fumes: a solution of nitrate of silver is obtained; as the solution cools, crystals are deposited.

2. To a solution of nitrate of silver add potassa: an ash-gray powder of oxide of silver falls.

3. To a very diluted solution of nitrate of silver add hydrochloric acid: chloride of silver falls in the form of a white, curdy substance, which soon becomes black upon exposure to the light.

4. Write upon linen with a solution of nitrate of silver, and, when the writing is dry, wash it with a solution of potassa: the writing soon becomes permanently black, owing to the formation of oxide of silver.

GOLD.

36. This metal is not affected by exposure to the air, and ordinary acids produce no action upon it.

EXPERIMENTS.

1. Put five or six gold leaves into a test tube; pour upon them a few drops of a mixture of nitric and hydrochloric acids; apply the flame of a spirit lamp: the gold leaves are dissolved. Continue to apply a gentle heat, so as to expel any excess of acid: terchloride of gold remains. In this process chlorine is set free from the hydrochloric acid, and combines with the gold.

2. Cover a slip of glass with a few drops of the terchloride of gold; apply the flame of a spirit lamp: the chlorine is expelled, and gold is left upon the glass.

3. Put a drop of chloride of mercury on a gold ring; with the point of a penknife touch the gold through the drop: a permanently white spot of an amalgam of gold is produced.

PLATINUM.

37. This metal is much used for making different kinds of chemical apparatus, on account of it being very infusible, and scarcely at all acted upon by ordinary chemical agents.

EXPERIMENTS.

1. Mix nitric acid with an equal bulk of hydrochloric acid; add the mixture to a few small pieces of platinum wire in a Florence flask; digest, — that is, keep the liquid at a slow boiling heat, — until the acid is neutralized: a solution of bichloride of platinum is formed.

To obtain it perfectly free from acid, evaporate cautiously to dryness, and dissolve the residue in water.

2. Add a drop of the solution of bichloride of platinum to a glass of water; into this solution let fall a drop of iodide of potassium: a deep port wine colored compound is immediately produced. The delicacy of this test is truly remarkable.

3. To the solution of bichloride of platinum add a solution of hydrochlorate of ammonia: a yellow precipitate is formed, a compound of this salt and platinum.

Decant the liquid, and dry the precipitate; put it into the bowl of a tobacco pipe, and bring it to a good red heat in the fire: metallic platinum, in a spongy state, is left, the other substances having been expelled by the heat.

4. Hold the spongy platinum before a stream of hydrogen gas: the metal soon becomes red hot, and the gas is ignited.

SECTION IV.

DOCTRINE OF EQUIVALENTS. CHEMICAL NOMENCLATURE, SYMBOLS, ETC.

38. When bodies combine with each other, it is always in certain fixed or definite proportions; that is, the same compound substance always contains the same elements combined in a constant proportion: thus water, whatever may be its quantity, or however generated, consists of 8 parts of oxygen to 1 part by weight of hydrogen: thus 1 part of hydrogen, combines with 16 parts by weight of sulphur, to form sulphuretted hydrogen: thus 1 part of hydrogen combines with 6 parts by weight of carbon, to form carburetted hydrogen, (olefiant gas.) The numbers representing the proportional weights in which bodies combine are called their *chemical equivalents.*

Taking 1 as the combining equivalent of hydrogen, 8 will be the combining equivalent of oxygen, 16 that of sulphur, and 6 that of carbon. Moreover, while 8 and 6 represent the proportional numbers in which oxygen and carbon respectively combine with hydrogen, these numbers also represent the proportion in which oxygen and carbon combine with each other or with any other substances: thus 8 parts of oxygen combine with 6 parts by weight of carbon, to form carbonic oxide. But this is not all: when the same bodies combine in more than one proportion, the proportional numbers representing each successive compound are multiples (or, it may be, submultiples) of those in the first compound. This law is exhibited in the following examples:—

Compounds of Carbon and Oxygen.

	Proportion of Carbon.		Proportion of Oxygen.		
Carbonic oxide - - -	6	+	8	=	14
Carbonic acid - - -	6	+	16	=	22

Compounds of Nitrogen and Oxygen.

		Proportion of Nitrogen.		Proportion of Oxygen.		
Protoxide of nitrogen	- -	14	+	8	=	22
Binoxide of nitrogen	- -	14	+	16	=	30
Hyponitrous acid	- - -	14	+	24	=	38
Nitrous acid	- - - -	14	+	32	=	46
Nitric acid	- - - -	14	+	40	=	54

The equivalent of a compound body is the sum of the equivalents of its elements: thus the equivalent of carbonic oxide is 14, this number being the sum of 6 and 8; thus the equivalent of nitric acid is 54, this number being the sum of 14 and 40.

39. The following table contains a list of the names of the elementary substances, so far as they are at present known, with their symbols and combining equivalents. Those substances printed in Italics are rare, and of comparatively little importance.

Table of Equivalents and Symbols of 62 Simple Substances.

Sym.	Name.	Equiv.	Sym.	Name.	Equiv.
H.	Hydrogen	1	Al.	Aluminum	14
O.	Oxygen	8	Fe.	Iron	28
N.	Nitrogen	14	Cu.	Copper	32
Cl.	Chlorine	36	Pb.	Lead	104
C.	Carbon	6	Zn.	Zinc	33
I.	Iodine	126	Cr.	Crome	28
S.	Sulphur	16	Hg.	Mercury	100
P.	Phosphorus	16	Ag.	Silver	108
F.	Fluorine	18	Au.	Gold	100
Br.	Bromine	78	Pl.	Platinum	98
B.	Boron	10	Sn.	Tin	58
Se.	*Selenium*	40	Co.	Cobalt	30
			Mn.	Manganese	28
	METALS.		Ni.	Nickel	30
K.	Potassium	40	Ba.	Barium	68
Na.	Sodium	24	Sr.	Strontium	44
L.	*Lithium*	6	As.	Arsenic	76
Ca.	Calcium	20	Sb.	Antimony	128
Mg.	Magnesium	12	Bi.	Bismuth	108
Si.	Silicon	8	Te.	*Tellurium*	64

Sym.	Name.	Equiv.	Sym.	Name.	Equiv.
V.	*Vanadium* - -	68	D.	*Didymium* - - -	?
U.	*Uranium* - -	60	Ln.	*Lanthanium* - -	48
Mo.	*Molybdenum* - -	48	Ce.	*Cerium* - - -	46
Tn.	*Tungsten* - -	94	Y.	*Yttrium* - -	32
Ti.	*Titanium* - -	24	Tb.	*Terbium* - -	?
Cm.	*Columbium* - -	184	E.	*Erbium* - - -	?
Nr.	*Niobium* - -	?	Cd.	*Cadmium* - -	56
Pe.	*Pelopium* - -	?	Pd.	*Palladium* - -	54
No.	*Norium* - -	?	R.	*Rhodium* - -	52
G.	*Glucinum* - -	26	Os.	*Osmium* - -	100
Zr.	*Zirconium* - -	34	Ir.	*Iridium* - -	98
Th.	*Thorium* - -	60	Ru.	*Ruthenium* - -	52

The arrangement of the elementary substances, in this table, is merely adopted to suit the order observed in the other portions of this work.

40. The first letter or letters of the Latin name of a simple substance is taken as its symbol; and the symbol of any substance always represents its combining equivalent. Thus O stands for one equivalent of oxygen; 2O, or O_2, stands for two equivalents of oxygen, and so on. Compounds are expressed by the equivalents of simple substances which enter into their composition: thus sulphuric acid is composed of one equivalent of sulphur and three equivalents of oxygen: the symbol of sulphuric acid, therefore, is $S + O_3$, or more simply SO_3, and the combining equivalent $= 16 + 3 \times 8 = 40$.

The sign of equality ($=$) is used to express an identity of *composition*, but not always an identity in the *form* of the arrangement of the elements.

The names given to compound substances are such as to indicate their elementary composition.

Compounds containing oxygen are called *acids* or *oxides*, according as they do or do not possess acidity. Thus an oxide of iron contains oxygen and iron. The termination *ic* is placed to the name of a substance when it becomes an acid: thus we have sulphur*ic* acid, which is a compound of sulphur and oxygen. When the substance forms two acids, that which contains the smallest portion of oxygen terminates in *ous;*

thus we have sulphur*ous* acid. The termination *uret* also indicates the combination of a variety of substances: thus we have sulph*uret* of iron, which expresses a compound of sulphur and iron. Degrees of oxidation are sometimes expressed by Greek or Latin prefixes: thus *prot*oxide expresses the first degree of oxidation, *bin*oxide the second, *ter*oxide the third, and so on. The highest degree of oxidation is usually expressed *per*oxide. When an acid, whose name ends with an *ic*, forms a salt, its name terminates with an *ate*: thus nitr*ic* acid forms a nitr*ate*; while a sulphur*ous* acid forms a sulph*ite*; and so on to other cases.

Exercises on the Use of Chemical Formulæ.

41. One of the greatest advantages of chemical formulæ is, that they enable us to represent chemical combinations and changes with such clearness and precision.

1. 1 eq.* water = 1 eq. hydrogen + 1 eq. oxygen
$= H + O$, or HO,
$= 1 + 8 = 9$.

2. 1 eq. carbonic acid = 1 eq. carbon + 2 eq. oxygen
$= C + O_2$, or CO_2,
$= 6 + 2 \times 8 = 22$.

3. 1 eq. nitric acid = 1 eq. nitrogen + 5 eq. oxygen
$= N + O_5$, or NO_5,
$= 14 + 5 \times 8 = 54$.

4. 1 eq. potassa = 1 eq. potassium + 1 eq. oxygen
$= K + O$, or KO,
$= 40 + 8 = 48$.

5. 1 eq. carbonate of potassa = 1 eq. potassa + 1 eq. carbonic acid
$= KO + CO_2$, or
$KO\ CO_2$,
$= 48 + 22 = 70$.

6. 1 eq. ammonia = 1 eq nitrogen + 3 eq. hydrogen
$= N + H_3$, or NH_3,
$= 14 + 3 \times 1 = 17$.

* Eq. is used as an abbreviation of the word *equivalent*.

7. 1 eq. hydrochloric acid = 1 eq. hydrogen + 1 eq. chlorine
$= H + Cl$, or HCl,
$= 1 + 36 = 37$.

8. 1 eq. hydrochlorate of ammonia $= NH_3 + HCl$
$= 17 + 37 = 54$.

9. 1 eq. bichloride of platinum $= Pl + 2Cl$, or $PlCl_2$,
$= 98 + 2 \times 36 = 170$.

10. 1 eq. lime = 1 eq. calcium + 1 eq. oxygen
$= Ca + O$, or CaO,
$= 20 + 8 = 28$.

11. 1 eq. carbonate of lime $= CaO + CO_2$, or $CaO\ CO_2$,
$= 28 + 22 = 50$.

12. The action in Exp. 3, Art. 12, is as follows: —

1 eq. carbonate of potassa + 1 eq lime
$= KO\ CO_2 + CaO$
$= KO + CaO\ CO_2$.

Here KO, or potassa, remains in solution, and $CaO\ CO^2$, or carbonate of lime, is precipitated.

13. The action in Exp. 1, Art. 14, is as follows: —

1 eq. sulphuric acid + 1 eq. water + 1 eq. zinc
$= SO_3 + HO + Zn$
$= ZnO\ SO_3 + H$.

Here $ZnO\ SO_3$, or sulphate of oxide of zinc, remains in solution, and the hydrogen is given off.

14. The action in Exp. 1, Art 13, is as follows: —

1 eq. hydrochloric acid + 1 eq. carbonate of lime
$= HCl + CaO\ CO_2$
$= CaCl + HO + CO_2$.

Here $CaCl + HO$, or chloride of calcium with water, is formed, and CO_2, or carbonic acid, is given off.

15. The action in Exp. 1, Art. 26, is as follows: —

1 eq. sulphate of magnesia + 1 eq. carbonate of potassa
$= MgO\ SO_3 + KO\ CO_2$
$= KO\ SO_3 + MgO\ CO_2$

Here $MgO\ CO_2$, or carbonate of magnesia, falls, and $KO\ SO_3$, or sulphate of potassa, remains in solution.

16. 1 eq. nitrate of copper, or nitrate of the oxide of copper,
$= 1$ eq. oxide of copper $+$ 1 eq. nitric acid
$= CuO + NO_5$, or $CuO\ NO_5$.

17. The action in Exp. 3, Art. 35, is as follows:—

1 eq. nitrate of the oxide of silver $+$ 1 eq. hydrochloric acid
$= AgO\ NO_5 + HCl$
$= NO_5 + HO + AgCl$.

Here NO_5, or nitric acid with water, remains in solution, and $AgCl$, or chloride of silver, falls.

SECTION V.

EXPERIMENTS CONDUCTED ON A LARGER SCALE, OR WITH A MORE COMPLETE APPARATUS.

OXYGEN — O.

42. *Preparation.*—To obtain oxygen pure, the substance which supplies it is placed in a retort or tube, and exposed to heat; when gas is evolved, it must be collected over water, either in the pneumatic trough or in a gas holder. (See pages 463 and 464.)

43. *Oxygen obtained from black oxide of manganese.*—This substance is used by itself when large quantities of the gas are required. The oxide is introduced into an iron bottle, to the mouth of which an iron

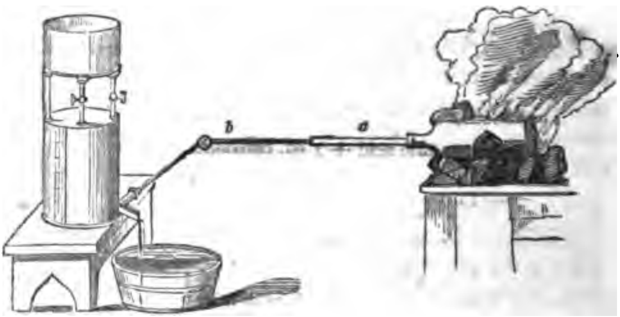


Fig. 21.

tube *a*, is adapted, and luted or plastered over with common pipe clay, made into paste with water. The extremity of this tube is luted to a flexible tube *b*, the outer end of which is inserted into the water of a

gas holder. The bottle is placed upon a good fire. When the manganese attains a red heat, it gives off a portion of its oxygen, which rises within the gas holder.

The chemical changes which take place in this process are exhibited in the following formulæ: —

$$3 \text{ eq. binoxide of manganese}$$
$$= 2MnO_2 = Mn_2O_4 = Mn_2O_3 + O.$$

Here, after the process is completed, Mn_2O_3, or sesquioxide of manganese, remains in the retort. The gas should stand for a short time over water, in order to absorb any carbonic acid gas which it may contain.

44. *Oxygen obtained from chlorate of potassa.* — Mix about equal parts of chlorate of potassa and black oxide of manganese in a mortar; introduce the mixture into a small copper or green glass retort; apply the flame of a spirit lamp, and receive the gas in the gas holder, or the pneumatic trough.

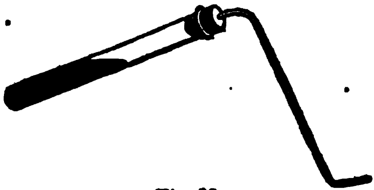


Fig. 22.

If only a small quantity of the gas is wanted, the mixture may be introduced into a large test tube, having a cork perforated by a bent exit tube, as in the annexed cut.

The decomposition is represented by the following formulæ: —

$$1 \text{ eq. chlorate of potassa}$$
$$= 1 \text{ eq. potassa} + 1 \text{ eq. chloric acid}$$
$$= KO + ClO_5 = KCl + O_6.$$

Here the heat resolves the chlorate of potassa into KCl, or chloride of potassium, and O_6, or 6 eqs. of oxygen. The manganese in the mixture merely aids in keeping a steady heat.

Experiments with Oxygen.

1. Introduce a lighted taper into a bottle of this gas: the flame is increased in size and brilliancy Introduce a candle with a wick red: it bursts into flame. (See Fig. 23.)

2 Put some pounded charcoal on a cup attached to a wire passing through a cork; heat the charcoal, over a spirit lamp, to redness; plunge it into the gas: the charcoal glows with great brightness, and bursts into flame. Here the product of combustion is carbonic acid gas. (See Fig. 24.)

3. Burn phosphorus in the same manner: it burns with great splendor.

4. Burn sulphur in the same manner: it burns with a beautiful blue flame.

5. Roll a piece of fine steel wire in a spiral form round a glass tube: fix one extremity of the wire in a cork, and to the other extremity

Fig. 23

Fig. 24.

Fig. 25.

attach a piece of cotton wick dipped in melted sulphur; ignite the wick, and plunge it into a bottle of oxygen: the wire takes fire, and burns with beautiful scintillations. The product of combustion in this case is oxide of iron. To prevent the bottle from breaking, the bottom should be covered with sand. (See Fig. 25.)

6. Introduce some dark-colored venous blood into a bottle of oxygen: the blood, upon being shaken, soon acquires the florid color of arterial blood.

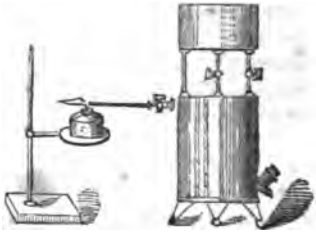


Fig. 26.

7. Project the oxygen from a gas holder on the flame of a spirit lamp: great heat is produced. Hold a small piece of chalk or lime before the flame: the light of the lime is brilliantly white and intense. Burn a piece of watch spring in the flame, &c.

8. Take a large piece of charcoal, and make a small hole in it; hold this part of the charcoal over a lamp until it becomes red hot; drop a small cast iron nail into the hole; hold the heated charcoal before a stream of oxygen (issuing from a jet with its orifice turned downwards:) the charcoal burns rapidly; the nail becomes white hot, then fuses, and finally burns, giving off a brilliant shower of ignited sparks of the metal. This is one of the most beautiful experiments in the whole range of chemistry.

Various other metals may be ignited in the same manner.

The common mouth blowpipe. — This consists of a brass tube, having a very small orifice or jet at one end, for projecting a small constant stream

of air upon the flame. In the flame of a common candle, *b* is a hollow cone containing combustible gases in excess; this is surrounded by a sheet of flame *a*, where the combustible material is in contact with the oxygen of the air. When we blow through this flame, by means of the blowpipe, the circumstances are completely changed; *b*, in the second figure, contains a powerful flame, having combustible gases in excess; this portion is called the *deoxidizing* or *reducing flame*, for it deprives substances of their oxygen; *a*, in the second figure, is a flame where the oxygen preponderates; this portion is called the *oxidizing flame*, for it communicates oxygen to the substance heated in it.

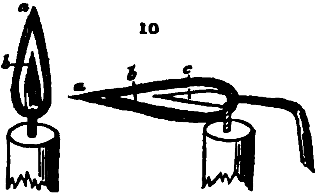


Fig. 27.

When a metal is to be brought to the state of an oxide, it is placed in the oxidizing flame *a*; and when an oxide is to be *reduced* to the metallic state, it is placed in the deoxidizing or reducing flame *b*. The most powerful heat is produced at the apex of the cone *c*.

In using the mouth blowpipe, the student must endeavor to acquire the power of keeping up a constant and steady blast, by forming his mouth into a bag of air, while at the same time he breathes through his nostrils. The manner of doing this is difficult to explain: by repeated trials, however, he will see that it is possible to do so.

Experiment. — Place one or two grains of oxide of lead (litharge) on a piece of charcoal, and hold the substance in the reducing flame *b*; the metallic lead is produced in the form of a brilliant globule; bring the globule to the oxidizing flame *a*; the metal is oxidized, and presents a dull appearance. Various other metals may be treated in the same manner.

The peculiar action of the flame of the blowpipe constitutes a most interesting and useful department of experimental chemistry.

HYDROGEN.

45. *Preparation.* — This gas is most conveniently prepared from zinc and diluted sulphuric acid. Put some zinc cuttings, sulphuric acid, and about five times the quantity of water, into a retort *r*, (see Fig. 14, page 463,) or into a bottle *b*, with the bent tube *t*; great heat is produced by the mixture of the acid and water, and the gas is copiously evolved, which may be received over water in the pneumatic trough or in the gas holder. (See Exercise 13, Art. 41.)

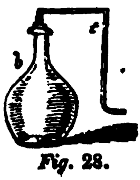


Fig. 28.

Experiments with Hydrogen.

1. Invert a jar of hydrogen over a candle; the flame of the candle is extinguished, but the gas burns at the mouth of the vessel. In this way the gas takes some time before it is burned away.

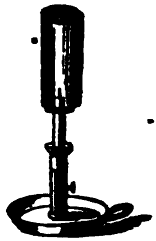


Fig. 29.

2. Ignite a jar or bottle of hydrogen, having the mouth of the vessel uppermost; in this case the gas burns much more quickly away, in consequence of its great lightness as compared with the air.

3. Introduce the gas into a jar *a*, having a gas burner *g*, and stop cock *c*; open the cock, and at the same time depress the jar in the water; ignite the gas as it issues from the small orifice *g*; the gas burns with a pale yellow flame, which gives off a great deal of heat.

Hold a dry glass tumbler over the flame: water is deposited.

Repeat Exp. 2, Art. 14.

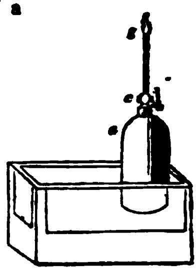


Fig. 30.

4. Mix in a strong bottle 1 measure of hydrogen with 2½ or 3 measures of common air; apply the flame of a candle to the mouth of the bottle: the mixture detonates with a considerable report.

5. Fill a bladder with this gas from a capped receiver at the pneumatic trough, as exhibited in the annexed cut, or from the gas holder; adjust a common tobacco pipe to the stop cock, and blow soap bubbles by giving a gentle pressure to the bladder: these soap bubbles, being filled with hydrogen, are lighter than the air, and they ascend in the atmosphere like little balloons. Bring the flame of a candle in contact with one of these hydrogen bubbles: it explodes.

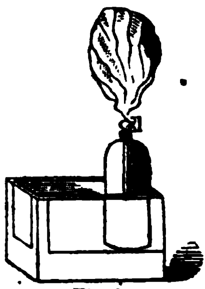


Fig. 31.

6. Fill a small balloon with hydrogen, or common street gas, and load it with a light paper car, so as to keep it suspended in the air.

7. Throw a stream of hydrogen on spongy platinum. (See Exp. 3, Art. 37.) To insure the success of the experiment, the platinum should be previously heated to redness before the spirit lamp.

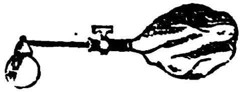


Fig. 32.

8. Mix over the pneumatic trough a portion of oxygen with twice its volume of hy-

drogen: fill a common soda water bottle full with the mixed gases; apply the flame of a taper: the gases detonate with a loud report.

Composition of Water.

46. It has already been explained that water is composed of 8 parts by weight of oxygen and 1 part of hydrogen. Now, oxygen is exactly 16 times heavier than hydrogen; hence it follows that there must be double the quantity by volume of hydrogen to form water. The composition of water may be determined in two ways: first, by *synthesis*, or by bringing the elements together; second, by *analysis*, or by separating the elements from each other.

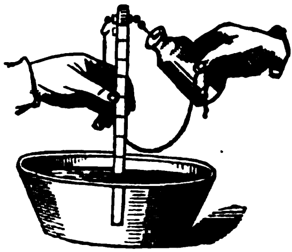


Fig. 33.

Synthesis. — Introduce the mixed gases, 2 volumes or measures of hydrogen and 1 volume or measure of oxygen, into a strong graduated tube (Volta's *Eudimometer*) having two wires nearly meeting each other within the tube at the top; pass an electric spark through the mixed gases by means of a charged Leyden jar, as shown in the annexed cut: the gases combine with ignition, water is formed, and a complete vacuum is produced, which is filled up by the ascent of the water in the trough.

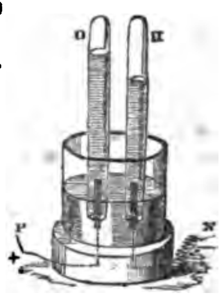


Fig. 34.

Analysis. — Two equal tubes, O and H, filled with water, are inverted over the two poles of a galvanic battery; when the battery is put in action the water is resolved into the two gases; the oxygen rises in the tube O placed over the positive pole, and the hydrogen into the tube H placed over the negative pole. As the analysis proceeds, it will be seen that the volume of the hydrogen is always double that of the oxygen.

47. Water is also decomposed by passing a current of steam through an iron tube partially filled with iron filings, and kept at a red heat by a furnace. In this cut, *r* represents the retort in which the water is being boiled; *t t* the red hot tube passing through the furnace F: the bent pipe *b* conveys the hydrogen gas into a jar *e* standing on the shelf of a pneumatic trough T. In this interesting experiment the steam passing over the heated iron is decomposed; the

iron, taking up the oxygen, becomes an oxide of iron, and the hydrogen is disengaged.

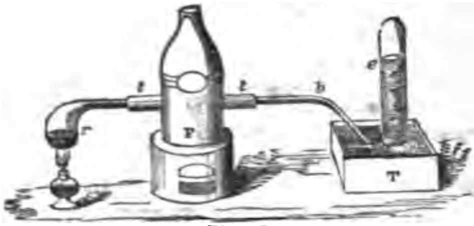


Fig. 35.

Ignition of the Mixed Gases. Oxy-hydrogen Blowpipe.

48. The simplest manner of showing the intense heat generated by the ignition of mixed gases is as follows: The hydrogen is formed in the bottle *b*, the cork of which is perforated by two tubes; *a* is a funnel-shaped tube, for the purpose of supplying sulphuric acid as it is required; *t* is a bent tube conveying the hydrogen for ignition; * *r* is the tube with a stop cock and jet, conveying a stream of oxygen from a gas holder on the hydrogen flame. The various experiments described in Art. 44 may be tried with this flame.

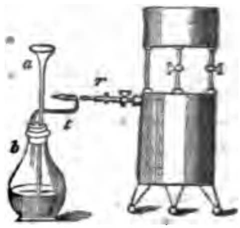


Fig. 36.

49. *Daniel's blowpipe.* — In this apparatus a common tube *b* receives the two gases contained in the bladders H

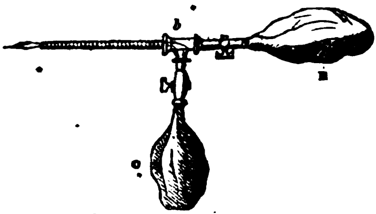


Fig. 37.

and O, provided with stop cocks. The hydrogen is first ignited, and then the pressure upon the bladder containing the oxygen is regulated so as to produce the maximum heating effect on the flame.

* This is an excellent arrangement for making hydrogen, as well as sulphuretted hydrogen, when large quantities are required.

50. The following economical apparatus, answering the double purpose of a gas holder and an oxy-hydrogen blowpipe, has been successfully used by the author of this work. In the annexed cut, *r* represents the gas receiver; *s* a shelf which screws on at *b*; *e* and *c* stop cocks, as in the ordinary gas holder, (see p. 464;) *h g* a jet filled with wire gauze at the thick part *h*; *p* an aperture for receiving the beak of a retort; *n k* a bent pipe passing into the interior of the receiver *r*; *k t* a flexible tube, which screws on at *k*, and forms a connection with a bladder containing the mixed gases; *f* a funnel with a tube and stop cock for screwing on at *k*. The tubular portion *d b* is about ¾ inch internal diameter and 2 inches in length. When the apparatus is to be used as an oxy-hydrogen blowpipe, water is introduced into the receiver, so as to stand at the level *d*; the orifice at *b* is closed by means of a cork, and the bladder containing the mixed gases is screwed on at *k*; the safety jet *h g* is screwed on the stop cock *e*; upon pressure being applied to the bladder, the mixed gases rise through the water, and filling the space *d b*, pass out in a strong stream through the jet *g*, and are there ignited. This arrangement is perfectly safe, for in the event of the flame passing along the safety tube *h*, we can only have an explosion of the gases contained in the small chamber *d b*, the only effect of which would be to blow out the cork in the orifice *b*, as the large body of water in *r* most effectually cuts off all communication with the gases in the bladder. When the apparatus is to be used as a gas holder, the shelf *s* is screwed on at *b*, the funnel *f* at *k*, and gases are received and transmitted in the same manner as in the ordinary gas holder.

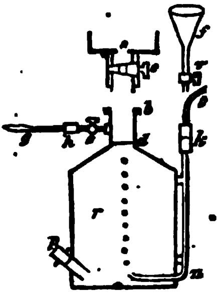


Fig. 38.

Analysis of Atmospheric Air by the Detonation of Hydrogen in Volta's Eudiometer.

51. Mix over the pneumatic trough 2 volumes of atmospheric air and 1 volume of hydrogen; introduce a small portion of this mixture into the eudiometer tube (Art. 46) so as to occupy 15 divisions of the tube; detonate by the electric spark: after detonation the gas only occupies 9 divisions of the tube; that is, 6 parts have disappeared, in consequence of all the oxygen having combined with a portion of the hydrogen to form water. Now, the gaseous mixture in the tube contained 10 parts of air and 5 of hydrogen; and since water is composed of 1 volume of oxygen and 2 volumes of hydrogen, one third of the diminution must

give the quantity of oxygen in the 10 volumes of air originally in the tube; that is, 2 volumes of oxygen have disappeared; but 2 is one fifth of 10; therefore one fifth of atmospheric air is oxygen, and the remaining four fifths are nitrogen: hence in 100 volumes of air, 20 are oxygen and 80 are nitrogen.

NITROGEN AND ITS COMPOUNDS WITH OXYGEN.

52. For the preparation and properties of nitrogen, see Art. 15, and Exps. 4 and 5.

Protoxide of Nitrogen — NO.

This gaseous compound is familiarly known by the name of the *laughing gas*, from the ludicrous effect which it has upon persons who respire it. This gas is not inflammable, but it supports combustion with greater brilliancy than common air.

Preparation. — Introduce some crystals of nitrate of ammonia * into a large retort; apply the heat of an Argand lamp having a copper flue, to give steadiness to the flame: at a temperature of 400° the salt fuses, and then gives off the gas in great abundance, which may be received in the gas holder filled with *warm* water, as cold water largely absorbs the gas. It should stand for two or three hours over a little water, to absorb any fumes of nitrous acid that may be formed in the process. The whole of the salt is resolved by heat into this gas and water, as shown by the following symbols:—

1 eq. nitrate of ammonia
= 1 eq. ammonia + 1 eq. nitric acid
$= NH_3 + NO_5$
$= H_3 + O_3 + N_2 + O_2 = 3HO + 2NO.$

Hence it appears that 1 eq. of nitrate of ammonia yields 3 eq. of water and 2 eq. of the protoxide of nitrogen.

EXPERIMENTS.

1. Plunge a burning candle into a bottle of this gas: the flame is much increased in brilliancy in consequence of the large quantity of oxygen which the gas contains.

* To prepare this salt, add carbonate of ammonia in powder to nitric acid diluted with about three parts of water until effervescence ceases; evaporate the solution until a drop of the liquid let fall upon a cold plate becomes a solid mass. A little ammonia should be added towards the close of the process to render the salt perfectly alkaline.

2. Introduce a large splinter of wood having a glowing red spark into this gas: the flame is rekindled, as in the case of oxygen gas.

3. Transfer this gas from the gas holder into a damp bladder having a wide wooden mouth piece;* place the mouth-piece between the teeth of the person who is to inhale the gas; let him close his nostrils with his fore finger and thumb, and then let him breathe the gas in the bladder: various effects, more or less ludicrous, are produced upon persons inhaling the gas. All kinds of apparatus should be removed, for they are liable to be injured by the inhaler; or better, let the inhaler be out doors.

Fig. 39.

Binoxide of Nitrogen — NO_2.

This compound is a colorless gas, similar in appearance to common air: it is sparingly absorbed by water.

Preparation. — Put some copper cuttings into a retort, pour nitric acid upon them, and then add about an equal quantity of water:* brisk effervescence takes place without the aid of heat, and the gas may be collected over water in the pneumatic trough.

The decomposition is represented by the following formulæ: —

4 eq. nitric acid + 3 eq. copper

$= 4NO_5 + 3Cu$

$= NO_2O_3 + 3NO_5 + 3Cu$

$= NO_2 + 3(CuO + NO_5)$

= binoxide of nitrogen + 3 nitrate of the oxide of copper.

Experiments.

1. Transfer a bottle of this gas over the pneumatic trough into a similar bottle nearly filled with common air; red fumes of nitrous acid (NO_4) are instantly formed, which are soon absorbed by the water. This constitutes a characteristic property of the binoxide of nitrogen, and it is used in this way to detect the presence of free oxygen.

2. Plunge a piece of burning phosphorus into a bottle of this gas: the phosphorus continues to burn.

3. Burn a mixture of this gas and hydrogen, (see cut to Exp. 3, Art. 45:) the mixed gases burn with a green-colored flame.

4. Transfer a bottle of binoxide of nitrogen to a cup containing a solution of sulphate of iron: the solution becomes black.

* The diluted acid should have a specific gravity of 1.2.

Nitric Acid — NO_5.

For the leading properties of this acid, see Art. 17.

Preparation. — Mix equal weights of nitrate of potassa (nitre) and oil of vitriol of commerce in a retort; heat the retort over a chauffer *a*, containing heated charcoal, (a sand bath or an Argand lamp would answer the purpose equally as well:) nitric acid distils over, and is con-

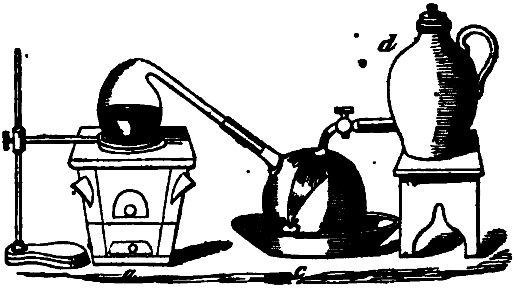


Fig. 40.

densed in the liquid form in the receiver *c*, kept cool by a stream of water proceeding from a jar *d*. The stream of water may be conveniently supplied from a funnel having its tube partially closed by a piece of rag.

The decomposition is as follows: —

2 eq. sulphuric acid + water + 1 eq. nitrate of potassa

$$= SO_3 + 2HO + KO\,NO_5$$
$$= KO\,2SO_3 + HO + NO_5 + HO$$

= bisulphate of potassa and water + nitric acid and water.

Distillations of any kind are conveniently effected by means of Liebig's condensing tube.

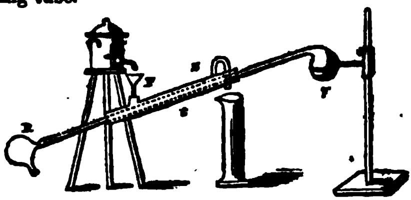


Fig. 41.

The liquid to be distilled is placed in the retort *r*, to which a sufficient heat is applied to boil the liquid: the vapor, as it passes along the tubes,

is condensed by the cold kept up in the condensing tube S t F, and the liquid drops into the receiver R. The construction of this condensing tube is exceedingly ingenious: t is a wide tin tube; F a funnel passing into it for the purpose of supplying cold water; S a siphon for carrying off the hot water; a glass tube passing through this tin tube is connected with the beak of the retort and the receiver R; this glass tube passes through perforated corks inserted at each end of the tin tube t. Now, this glass tube is continually surrounded by cold water; for while cold water is being supplied by the funnel F, the water, as it becomes heated, rises within the tin tube, and is carried off by the siphons.

Experiment. — Heat gently some oil of turpentine in a porcelain basin; pour suddenly upon it a mixture of one part of sulphuric acid and two parts of nitric acid: combustion takes place, with the evolution of a dense smoke. In order to avoid accident, the mixed acid should be poured from a bottle tied to the end of a stick.

CARBON, SULPHUR, AND PHOSPHORUS, THEIR COMPOUNDS WITH OXYGEN AND HYDROGEN.

Carbonic Oxide — CO.

53. This is a colorless gas; it is the gas that burns with a blue flame at the top of a coke or charcoal fire.

Preparation. — Mix pounded oxalic acid with sulphuric acid in a retort, and apply heat: carbonic oxide and carbonic acid gases are given off, which may be received over the pneumatic trough. By allowing the gases to stand over water for a few hours, or by agitating them with lime water, the carbonic acid gas is absorbed, and the carbonic oxide is left pure. Oxalic acid may be regarded as a compound of carbonic oxide and carbonic acid with water; thus: —

1 eq. oxalic acid $= C_2O_3 +$ water $= CO + CO_2 +$ water. Now, the sulphuric acid combines with the water, and sets the two gases free.

Experiment. — Plunge a lighted taper into a bottle of this gas: the taper is extinguished, but the gas burns at the mouth of the bottle with a beautiful blue flame: thus *carbonic oxide is inflammable, but it does not support combustion.*

Carbonic Acid — CO_2.

54. *Preparation.* — Carbonic acid gas, being more than 1½ times heavier than common air, may be prepared sufficiently pure by the following process. The gas is generated in the bottle b (see Exp. 1, Art. 13;) a bent tube b c d passes through a cork b, and descends to the bottom of

the open bottle *d*: as the gas enters the bottle *d*, the common air is displaced.* A little experience will readily enable the experimenter to ascertain when the bottle is filled with the gas.

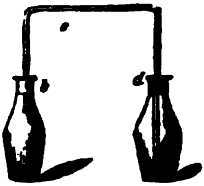


Fig. 42.

When this gas is received over the pneumatic trough, the water should be warm; for carbonic acid gas is largely absorbed by cold water.

EXPERIMENTS.

1. Invert a jar or bottle of the gas over a burning candle: the gas by its gravity falls upon the candle, and extinguishes the flame.

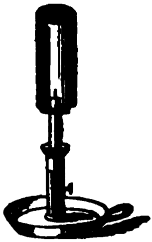


Fig. 43.

2. Place a burning candle in an open jar; take a bottle of carbonic acid gas, and pour it into the jar: the flame is extinguished. This shows that carbonic acid gas is much heavier than common air.

3. Pour some lime water into a bottle containing this gas: carbonate of lime is formed: shake the liquid, and it becomes clear, in consequence of the carbonate of lime being soluble in an excess of carbonic acid. In this way lime is dissolved in spring water.

4. Add a little water to a bottle of the gas; shake the bottle; the water takes up the gas, and acquires decided acid properties; add a little solution of litmus: the blue is changed to red.

Carburetted Hydrogen — CH_2.

55. This gas is formed in marshes and stagnant pools; it is but little more than half the weight of common air; it is highly inflammable, and forms the *fire damp* of the miners. When coal is heated to redness, it is resolved into tarry matter, and certain gaseous compounds of carbon and hydrogen, containing about seventy per cent. of carburetted hydrogen.

EXPERIMENTS.

1. Invert a bottle filled with water in a stagnant pool; insert a funnel into the bottle to catch the gas; stir up the bottom of the pool with a stick: bubbles of carburetted hydrogen gas rise, which are easily received through the funnel. Ignite the gas thus obtained: it burns with a yellow flame.

* Gases which are lighter than the air, such as ammoniacal gas, may be received in bottles with their mouths inverted.

2. Mix 1 measure of this gas with 7 or 8 of common air, in a bottle; apply the flame of a candle: the gas explodes with some violence. Mix 1 measure of the gas with 3 or 4 measures of air, and ignite the gases: they burn without explosion.

3. Put some pounded coal into a test tube, fitted with a cork and the stem of a tobacco pipe; apply the flame of a spirit lamp: gas is disengaged, which may be inflamed as it issues from the small orifice of the pipe.

4. The flame of a candle is produced by the ignition of carburetted hydrogen gases. Bring one extremity of a tube, about $\frac{1}{8}$ of an inch in diameter, into the centre of the flame of a candle: the gases rise up the tube, and may be ignited as they escape at the upper end. This experiment also shows that flame is hollow.

Fig. 44.

56. *The Davy lamp.* — Carburetted hydrogen occurs in coal pits, from the decomposition of the coal, where it sometimes explodes by coming in contact with flame; and thus melancholy accidents take place. The Davy lamp is designed to prevent these explosions.

Experiment. — Take a piece of fine wire gauze: hold it across the flame of a lamp; the flame does not pass through the gauze. Blow out the flame, and ignite the smoke as it rises through the gauze: the flame does not descend below the gauze.

Fig. 45.

Fig. 46.

This experiment exhibits the principle upon which the Davy lamp is constructed: the metal, being a high conductor of heat, cools down the temperature of the inflammable matter in contact with it, and thereby extinguishes the flame on the side opposite to the burning body. The Davy lamp simply consists of a lamp surrounded by wire gauze to pre-

vent flame extending from the interior of the lamp to the adjacent atmosphere.

Olefiant Gas, or Heavy Carburetted Hydrogen — C_4H_4.

57. This gas, owing to its illuminating power, is the most valuable constituent of street gas. It contains a larger quantity of carbon than the light carburetted hydrogen. Coal gas, when well prepared, contains about 20 per cent. of olefiant gas.

Preparation. — Mix one part of alcohol with 5 or 6 parts of sulphuric acid in a retort; apply the heat of an Argand lamp: the gas comes over in great abundance, which may be received over water in the pneumatic trough.

EXPERIMENTS.

1. Plunge a lighted candle into a bottle of this gas: the flame of the candle is extinguished; but the gas burns, at the mouth of the bottle, with a fine, brilliant flame.

2. Burn this gas in a capped receiver. (See cut to Exp. 3, Art. 45.)

3. Mix 3 volumes of oxygen with 1 volume of olefiant gas in a strong common soda water bottle; ignite the mixed gases: a violent explosion takes place, carbonic acid and water being formed: thus we have

olefiant gas and oxygen

$$= C_2H_2 + O_6 = 2CO_2 + 2HO.$$

1. Mix 2 measures of chlorine with 1 measure of olefiant gas in a bottle; introduce a lighted candle: the gases burn with a red flame, with a copious deposition of lampblack, thereby showing that olefiant gas contains carbon.

Sulphurous Acid — SO_2.

58. This acid may be procured in a pure state by boiling in a retort sulphuric acid with copper cuttings: the gas may be received by displacement, as in Art. 54. The action is represented by the following symbols: —

2 eq. sulphuric acid + 1 eq. copper
$= 2SO_3 \quad + CU$
$= SO_2 \quad + CuO\,SO_3$
= sulphurous acid + sulphate of oxide of copper.

By passing a current of the gas through water, a solution of sulphurous acid is obtained. It unites with bases, forming sulphites. The gas is used in bleaching woollens

Sulphuric Acid — SO_3.

59. This valuable acid is made by the manufacturer on a large scale, by burning sulphur in a furnace, where nitric acid is, at the same time, formed by the decomposition of nitrate of soda by means of sulphuric acid: the sulphurous and nitric acids pass into a succession of leaden chambers containing a portion of water, to dissolve the sulphuric acid, as it is being formed by the nitric acid giving up a portion of its oxygen. In the annexed cut, *a* represents the furnace in which the sulphurous

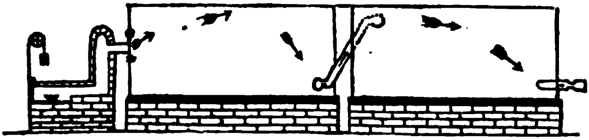


Fig. 47.

and nitric acids are formed; *b b* the leaden chambers containing some water. The sulphur is spread over the bottom of the furnace, and the nitre is placed in the cup, shown in the cut. The second chamber communicates with a high chimney, for creating a draught, and also for carrying off the surplus vapors.

Sulphuretted Hydrogen, or Hydrosulphuric Acid — HS.

60. *Preparation.* — Heat sulphuret of antimony in a retort, with 4 or 5 times its weight of hydrochloric acid, and collect the gas over warm water in the pneumatic trough, (or by displacement, as in Art. 54.). As the bottles are filled with the gas, they should be speedily removed and closed.

The action is represented in the following symbols: —

1 eq. sesquisulphuret of antimony + 3 eq. hydrochloric acid
$= Sb_2S_3 + 3HCl$
$= 3HS + Sb_2Cl_3$
= 3 eq. sulphuretted hydrogen + 1 eq. sesquichloride of antimony.

Experiments.

1. Invert a jar of this gas; apply a lighted match: the gas burns with a pale blue flame with the deposition of sulphur.
2. Pour a few drops of strong nitric acid into a bottle of this gas,

and immediately close the mouth with the thumb, protected by a piece of paper: an explosion takes place with the deposition of sulphur.

3. Generate the gas in a flask fitted with a cork and bent tube passing into a solution of arsenious acid, (arsenic of commerce:) an orange-colored precipitate is formed of a sulphuret of arsenic. Sulphuretted hydrogen is much used in this way as a test for metals.

4. Transmit, as in the last experiment, a current of the gas through liquid ammonia: a solution of hydrosulphuret of ammonia is formed. This solution is much used as a re-agent.

Fig. 48.

Phosphuretted Hydrogen — PH_3.

61. *Experiment* 1. — Put some thin slices of phosphorus into a small retort, and fill it completely with a mixture of *lime* and warm water; insert the beak of the retort in a vessel containing warm water; boil the

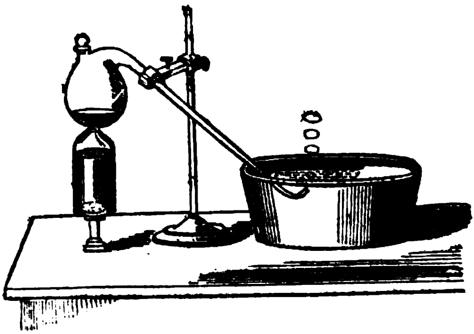


Fig. 49.

mixture: bubbles of phosphuretted hydrogen gas are given off, which, escaping into the air, ignite spontaneously, and form beautiful rings of smoke.

2. Invert a test tube filled with water over the beak of the retort in which the gas is being formed: the tube is soon filled with the gas. Observe that the gas is colorless and transparent like common air; cover the mouth of the tube with the fore finger, and transfer the gas into a jar of oxygen standing on the shelf of the pneumatic trough; the bubbles, as they rise into the jar, catch fire, giving a splendid flash of light.

CHLORINE — Cl.

62. *Preparation.* — Introduce into a retort hydrochloric acid and black oxide of manganese, so as to form a thin paste; heat the mixture with an Argand lamp: chlorine gas is speedily given off, which may be recognized by its peculiar color and suffocating odor; receive the gas over warm water in a small pneumatic trough, (or by displacement; see Art. 54.) The action is represented by the following symbols: —

2 eq. hydrochloric acid + 1 eq. oxide of manganese
$= 2HCl + MnO_2$
$= \quad Cl + MnCl + 2HO$
= 1 eq. chlorine + chloride of manganese and 2 eq. water.

EXPERIMENTS.

1. Repeat Exp. 1, Art. 22.
2. Let fall powdered antimony into a bottle of this gas; the metal ignites spontaneously, and forms a beautiful shower of flame. Various other metals ignite spontaneously in this gas, and form *chlorides*.
3. Put a piece of red calico moistened with water into a bottle of chlorine: the color is speedily discharged.

Hydrochloric Acid — HCl.

63. To obtain this acid in the gaseous state, introduce into a retort common salt and as much sulphuric acid as will form a thin paste; apply the flame of an Argand lamp, and receive the gas by displacement, as it is highly soluble in water. (See Art. 54.)


Fig. 50.

Experiment. — Place a bottle of this gas over a bottle of ammoniacal gas: the gases combine and form dense white fumes of hydrochlorate of ammonia.

Liquid hydrochloric acid may be prepared in considerable quantities by transmitting a current of the gas through water; it may also be made on a small scale, after the manner of preparing nitric acid, (see page 492,) taking care in this case to put water into the receiver *b*.

Cyanogen — Cy, *or* C_2N.

64. *Experiment.* — Introduce a few grains of cyanide of mercury (HgCy) into a test tube fitted with a cork and bent tube; apply the

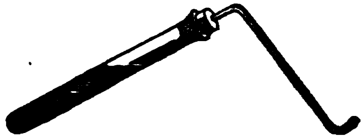


Fig. 51.

flame of a spirit lamp: cyanogen gas is given off; ignite the gas as it issues from the small tube: it burns with a beautiful violet flame.

Section VI.

COMPOSITION OF VEGETABLE SUBSTANCES. COMPOUND ORGANIC SUBSTANCES IN PLANTS. FERMENTATION. DIASTASE. GERMINATION OF PLANTS. STRUCTURE AND FUNCTIONS OF PLANTS. FOOD OF PLANTS.

COMPOSITION OF VEGETABLE SUBSTANCES.

65. When a piece of straw, or any dried vegetable substance, is held in the flame of a candle, the greater portion is consumed in the form of gases, and only a very small portion, called the ash, is left behind. That portion which burns away is called the *organic* part of the plant, and that which remains, the ash, is called the *inorganic* part. The organic part of plants consists of four elementary substances, viz., carbon, oxygen, hydrogen, and a small quantity of nitrogen. The inorganic part consists of the following earthy substances, viz., potassa, soda, lime, silica, magnesia, alumina, oxide of iron, oxide of manganese, sulphuric acid, phosphoric acid, and chlorine. Although the ash forms a very small part of plants, yet it seems to be as essential to their growth and existence as any of the elements composing the organic part. The proportion in which these substances are found varies in different plants, and even in different parts of the same plant. The following tables, by Boussingault and Johnston, give the composition of the organic as well as of the inorganic parts of some of our most valuable plants.

When all moisture has been evaporated, 100 lbs. of each vegetable substance is composed as follows:—

	Carbon.	Oxygen.	Hydrogen	Nitrogen.	Ash.	
Wheat,	46·1	43·4	5·8	2·3	2·4	100
Oats	50·7	36·7	6·4	2·2	4·0	100
Peas.	46·5	40·0	6·2	4·2	3·1	100
Potatoes,	44·0	44·7	5·8	1·5	4·0	100
Wheat Straw,	48·4	38·9	5·3	0·4	7·0	100
Oat Straw,	50·1	39·0	5·4	0·4	5·1	100
Pea Straw,	45·8	35·6	5·0	2·3	11·3	100

In 100 lbs. of ash we have the following composition:—

	Wheat.	Oats.	Barley.	Wheat Straw.	Oat Straw.
Potassa	19	0·0	12	0·50	15
Soda,	20·5	5·0	12	0·75	trace
Lime,	8	3·0	4·5	7·00	2·75
Magnesia,	8	2.5	8	1·00	0·50
Alumina,	2	0·5	1	2·75	trace
Oxide of Iron,	0	1·5	trace	0	trace
Silica,	34	76·5	50	81·00	80·00
Sulphuric Acid,	4	1·5	2·5	1·00	1·50
Phosphoric Acid,	3·5	3·0	9	5·00	0·25
Chlorine,	1	0·5	1	1·00	trace
	100	100	100	100	100

66. Hence it appears that different kinds of plants must exhaust the soil of different proportions of inorganic matter; thus, for example, 100 lbs. of the ash of wheat carry off 19 lbs. of potassa and 34 lbs. of silica, while that of barley only 12 lbs. of potassa and as much as 50 lbs. of silica.* Thus it is that some land will suit one kind of vegetables and not another kind; and hence it is that two successive crops of *different* kinds of plants may grow on land, when two successive crops of the *same* kind would exhaust the soil of some of its most essential constituents. It has, however, been found, that when any one of the alkalies is absent from the soil, its place may be, to a certain extent, supplied by another alkali without injury to the vegetation: thus, when a soil is deficient in potassa and

soda, then lime (an alkaline earth) will in some measure supply their place in the ash of the plant.

67. As plants carry off, year after year, certain portions of organic as well as inorganic substances from the land in which they grow, it becomes necessary, in most soils, that these substances should be restored to the land in the form of manures.

COMPOUND ORGANIC SUBSTANCES IN PLANTS.

68. In the organic part of plants, the four elements of which it is composed are found in the plant in the form of distinct compounds; the most abundant of these are lignine or woody fibre, starch, gum, sugar, gluten, and albumen. The first four substances are composed of carbon and water only, and the last two substances contain nitrogen, in addition to carbon, oxygen, and hydrogen.

The composition of the first four substances is as follows:—

		Composition	may be represented.
Lignine	-	$C_{12}\,H_8\,O_8$	12 eq. carbon and 8 eq. water.
Starch	-	$C_{12}\,H_{10}\,O_{10}$	12 eq. carbon and 10 eq. water.
Gum	-	$C_{12}\,H_{11}\,O_{11}$	12 eq. carbon and 11 eq. water.
Grape Sugar		$C_{12}\,H_{12}\,O_{12}$	12 eq. carbon and 12 eq. water.

The only difference in the composition of these compounds is, that they contain different proportions of the elements of water.

Most of vegetable compounds are characterized by the following circumstances: 1. By being composed of the same elements; 2. By the facility with which they undergo decomposition; 3. By the facility with which many of them are converted into each other, especially when a substance containing nitrogen is present; 4. By the impracticability of forming them by the direct union of their elements.

These distinct compounds, which exist ready formed in the vegetable, are called *proximate principles;* thus sugar and gum are proximate vegetable principles.

Experiment.—Put some wheat flour in a fine muslin bag, and knead or work it with your fingers, while a small stream of water is poured

upon it; continue the process until the water ceases to be milky: the substance remaining in the bag is a gray adhesive matter like bird lime, called *gluten;* allow the milky portion which has been washed from the bag to subside; decant the clear liquid: the white deposition is called *starch;* take the clear liquid and boil it: white flakes of *albumen* are formed, a substance very similar in its nature to the white of an egg. Gum and sugar are dissolved in the water.

Perform the same process with grated potato: in this case, fibrous matter is left in the bag, the other portions being the same as in the preceding experiment.

69. Lignine, starch, gum, and sugar, being so similar in composition, may readily be converted into each other. Thus, for example, starch may be converted into gum by roasting at a temperature above that of boiling water; lignine may be converted into gum by the action of strong sulphuric acid; and the gum thus formed may be converted into sugar by adding water, and boiling the mixture for some hours; and so on to other cases of transformation.

EXPERIMENTS.

1. Dissolve some starch in boiling water: a thick jelly is formed, which, after being dried, has the appearance of glue; this jelly is insoluble in cold water, and is rendered blue by the addition of a solution of iodine. (See Exp. 2, Art. 21.) To the thick solution of starch add an infusion of vegetated barley of the malting: the starch grows more liquid, and in a short time its consistence entirely disappears; evaporate to dryness, and a *yellow* jelly-like mass is obtained, which is now readily dissolved by *cold* water, whereas starch is insoluble in *cold* water. To a solution of this substance add a solution of iodine: a red wine color is produced. This yellow substance is a gum called *dextrine;* it is used in the place of gum arabic for stiffening calico. There is evidently some active agent in the vegetating barley, which has produced these changes in the starch: this agent has been called *diastase.*

2. Boil some diluted sulphuric acid (1 part of acid to 12 parts of water) in a porcelain dish; add gradually some starch paste: the starch is dissolved; test a portion of the solution by means of a solution of iodine: a red wine color is produced, as in the last experiment; continue the boiling for a short time longer, and the iodine will cease to produce any change of color. Take the liquid in the evaporating dish, and add to it powdered chalk until the acid is neutralized, and allow

the sulphate of lime to subside: the clear liquid is sweet, and crystals of *sugar* may be obtained by evaporating a portion of the water by a slow heat. In this process no gas is given off, and the acid suffers no change. The only difference in the composition of starch and sugar is, that the latter contains more of the elements of water than the former.

Berzelius designates this peculiar action exerted by the sulphuric acid in converting starch into sugar the *catalytic force*, or the force of *catalysis*.

70. *Fermentation.* — This term is used *generally* to express those changes that are spontaneously effected in organic substances by the reaction of their elements. Thus, when a solution of grape sugar, to which ferment or common yeast has been added, is kept for some time at a moderate heat, the mixture froths up, in consequence of the escape of carbonic acid gas, the sweet taste of the solution gradually disappears, and when the *fermentation* has ceased, spirit, or alcohol, is found in the water. This spirit is given off in a concentrated form by evaporation at a temperature below that of boiling water. Alcohol ($C_4H_6O_2$) contains less oxygen and carbon than sugar; hence the escape of carbonic acid in order to change the sugar into *alcohol.* Thus sugar, or $C_{12}H_{12}O_{12}$, becomes $2C_4H_6O_2$, or 2 eq. alcohol and $4CO_2$, or 4 eq. carbonic acid. Yeast, as well as all substances which have the property of *inducing* or exciting fermentation, contains nitrogen, in addition to carbon, oxygen, and hydrogen.

71. When a mixture of diluted spirit and yeast is exposed to the air, oxygen is absorbed, and *acetic acid* or vinegar is formed. The composition of dry acetic acid is $C_4H_3O_3$; that is, it may be represented by 4 eq. carbon and 3 eq. water. Hence the action may be represented as follows: —

$$\begin{aligned} \text{1 eq. alcohol} + \text{4 eq. oxygen} &= C_4H_6O_2 + O_4 \\ &= C_4H_3O_3 + 3HO, \end{aligned}$$

or 1 eq. acetic acid + 3 eq. water.

In both of these cases of fermentation the yeast merely acts as a stimulating agent.

72. Besides the proximate vegetable principles already

enumerated, there are several vegetable acids, oils, fatty matters, and the peculiar substance called diastase, which produces an important action in relation to the growth of plants.

Vegetable acids. — The most common vegetable acids are, acetic acid (vinegar), malic acid (the acid of apples), oxalic acid (from common sorrel), tartaric acid (in grapes), citric acid (the acid of lemons).

GERMINATION. DIASTASE.

73. When a seed is planted it begins to sprout; that is, it shoots a sprout upwards into the air, and sends a root downwards into the soil. At this stage of the life of the young plant it must live upon the starch and gluten contained in the seed alone. In order to render these substances soluble in water, and thereby available for the food of the plant, there is formed out of the gluten, at the base of the germ, the peculiar substance called diastase. This substance renders the starch soluble in the sap, and it is thus conveyed to the shoot and root of the young plant. The starch in this state of solution becomes sugar. As the plant advances in its growth it begins to have leaves, and at this stage the sugar is changed into woody fibre, which forms the stem. By the time the starch and gluten are exhausted from the seed, the plant has acquired all the functions necessary for taking up food from the air and the soil. A similar process takes place in the formation of malt, where the germination of the barley is stopped when the sugar is formed.

STRUCTURE AND FUNCTIONS OF PLANTS. FOOD OF PLANTS.

74. A complete plant has three parts which are essential to its growth: a root, which throws out fibres into the soil; a trunk or stem, which rises into the air; and leaves, which present an extended surface to the action of the air. Each of these three parts performs peculiar functions or offices in the growth of the plant.

1. The *trunk*, or stem, consists of three parts: in the centre

is the *pith*, next the pith is the *wood*, and the *bark* encloses the whole.

The *pith* consists of very small horizontal tubes; the *wood* and *inner bark* are made up of longitudinal tubes connected together for conveying the sap between the roots and leaves; the vessels in the wood convey the sap from the roots to the leaves, and the vessels in the inner bark convey the sap from the leaves to the roots; thus in a growing plant there are currents of sap continually ascending and descending.*

2. The *root* on leaving the stem has the same structure as the trunk; but the finely-extended tendrils consist of one white, uniform, spongy mass, for the purpose of absorbing liquid food from the soil.

3. The *leaf* consists of fibres, which are continuations of the wood, together with the green portion, which is a continuation of the bark. The under part of the leaf is full of pores, which communicate with the hollow tubes of the inner bark. It has already been explained (Exp. 6, Art. 15, and Art. 18) that in the daytime the leaves are continually absorbing carbonic acid gas from the air, and throwing off oxygen; thus carbonic acid is decomposed by the plant — the carbon is retained as food, while the oxygen is rejected. The reverse of this process is going on at night, but so slowly as scarcely to interfere with the general effect. Carbonic acid also enters the plant through the roots. Some *suppose* that carbon enters the plant by the roots in the form of *ulmic acid*, a substance composed of carbon and water only.

75. The elements composing the organic part of plants are always absorbed in a state of combination, and the substances forming the inorganic part must be in a state of solution, in order to be sucked in by the roots. The food of plants must contain the various elements which enter into their composition. In general, the substances which afford this food are

* The ascent of the sap probably, in some measure, depends on the principle of *endosmose* and *exosmose*. (See Art. 39, p. 89, of the Treatise on Hydrostatics.)

carbonic acid, water, and ammonia, derived from the air as well as the soil; and certain saline and earthy substances, derived exclusively from the soil. Light and heat (and probably electricity) stimulate the functions of plants, and are absolutely necessary to their growth and full development. Light is also essential to the formation of the coloring matter in plants.

It will now be easy to see how the plant should form woody fibre, starch, sugar, gum, or vinegar, all of which substances consist of carbon and water only, united in different proportions. Ammonia and nitric acid supply the plant with nitrogen.

SECTION VII.

SOILS. THEIR COMPOSITION. ORGANIC AND INORGANIC PARTS. SALINE AND EARTHY PARTS. PHYSICAL CHARACTER OF SOILS. TO SEPARATE THE SAND FROM THE CLAY. TO DETERMINE THE QUANTITY OF LIME, OF ORGANIC MATTER, AND OF SALINE MATTER, IN A SOIL. ORIGIN OF SOILS. MECHANICAL PROPERTIES OF SOILS. CHEMICAL PROPERTIES OF SOILS.

COMPOSITION OF SOILS.

76. Soils, like plants, are composed of organic as well as of inorganic matter.

The *organic part of soils* is chiefly derived from the remains of vegetable and animal substances. Peaty soils contain a large proportion of organic matter, while good wheat lands contain only about one twentieth of their whole weight. This organic matter in the soil has been called *humus*, which, by the action of alkaline substances, is resolved into ulmic and humic acids. As the vegetable matter undergoes decay, this organic portion of the soil also gives to the land the various inorganic substances found in its ash.

77. The *inorganic part of soils* consists of certain *saline*

soluble substances, and of certain *earthy* insoluble substances.

1. The *saline soluble substances* consist, in general, of common salt, sulphates of soda and magnesia, gypsum, with small portions of the nitrates of potassa, soda, and lime, and of the chlorides of calcium, magnesium, and potassium, together with ammoniacal salts. From these soluble compounds the plant obtains nearly all the saline matter contained in its ash. The rain dissolves these saline substances, and carries them into the subsoil; but in dry, warm weather, they reascend to the surface, and are thus brought in contact with the roots of the growing plant. Thus fine warm weather accelerates the ripening of corn and other valuable grain.

2. The *earthy insoluble substances* in the soils never constitute less than nine tenths of their whole weight. The *principal* ingredients of this earthy matter are *silica*, in the form of sand, *alumina*, mixed with sand, in the form of *clay*, and *carbonate of lime*. Where the soil has a red color, the *oxide of iron* is generally present. Minute traces of *phosphate of lime* may also be detected in most good soils.

PHYSICAL CHARACTER OF SOILS.

78. The relative proportions of sand, clay, and lime in a soil give it a peculiar physical character. When a soil contains only a small proportion of clay, it is called a *sandy soil;* when the quantities of sand and clay are nearly equal, it is called a *loamy soil*, or *clay loam*, according as the quantity of sand is greater or less than the clay; when the clay is much in excess, it is called *clay loam*, or *strong clay*, as the case may be. Good arable land rarely contains more than one third part of its weight of clay.

79. *To separate the sand from the clay in a soil.* — Take about half an ounce of soil, and boil it in about half a pint of water, in a porcelain dish, until it is completely diffused through the water; after shaking, let the mixture stand for a minute, to allow the sand to settle to the bottom of the vessel, while the clay remains suspended in the fluid;

pour off the water with the floating clay into another vessel, and allow the clay now to settle. The sandy portion of the soil will be found in the first vessel, and the clayey portion at the bottom of the second. The sand and clay may now be dried and weighed separately, and the relative weights will give the proportion in which they subsist in the soil.

80. If a soil contains more than one twentieth of its weight of carbonate of lime, it is called *marl;* and if more than one fifth, it is called *calcareous soil.*

To determine the quantity of lime in a soil. — Take 100 grains of the soil, (which has been previously heated to redness, to destroy the vegetable matter,) and diffuse it through about half a pint of distilled water; add about an ounce of hydrochloric acid, and allow the mixture to stand for a few hours, observing to stir it from time to time. Bubbles of carbonic acid are given off. After the action has ceased, pour off the clear liquid; dry and then heat the residue to redness, and weigh it: the loss is nearly the weight of lime and carbonate of lime in the soil.

81. *To determine the quantity of organic matter.* — Dry about an ounce of the soil on paper in an oven, at a heat which does not char the paper; burn about 200 grains of this dry soil: the loss is nearly the weight of the organic matter contained in it.

82. *To determine the quantity of saline matter.* — Take 2 lbs. of dry soil, and boil it in about a quart of distilled water; after allowing the solid matter to subside, pour off the clear liquid, and evaporate to dryness at a moderate heat; weigh the residue, and it will give the quantity of soluble saline matter in the soil. In a good soil this saline matter may weigh, upon an average, about 20 grains.

ORIGIN OF SOILS.

83. Soils owe their origin to the disintegration or gradual crumbling down of rocks, by the action of water, frost, air, and various chemical agents. Hence soils, in general, derive their peculiar character from the geological strata upon which they lie, or from the nature of the rocks in the adjacent hills or mountains.

MECHANICAL PROPERTIES OF SOILS.

84. Sandy and marly soils are heavy, while peaty soils are light. Strong clays and peaty soils absorb and retain moisture; hence they are damp and cold; hence, especially, the

necessity for draining such soils. Sandy soils neither absorb nor retain much moisture; hence such soils become scorched with the heat of summer, and the plants growing upon them are burned up. In rainy seasons, however, sandy soils frequently sustain a luxuriant vegetation, while the plants upon a clayey land almost perish from the excess of moisture.

85. Heat causes clay and peat to contract; in doing so, the soil compresses the roots of the plants, and prevents the access of air, and thus the growth of the plant is retarded.

86. The absorbent power of clay is useful in a soil, for during the hot and dry season of the year, in the cool period of the night, the clay absorbs the dew that falls upon it, and retains the moisture with great tenacity.

87. In order that plants may come to perfection, it is necessary that the soil on which they grow should attain a certain degree of warmth. Damp lands are cold, for the continual evaporation of the moisture carries off the heat of the sun; hence the necessity of drainage.

88. These observations show the value of a due admixture of clay and sand in order to form a mixture having all the mechanical qualities of a fertile soil, where the earthy constituents are so adjusted that "the loose and porous qualities of the one are corrected by the plastic and retentive qualities of the other." It is a remarkable fact, that a mixture of alumina, silica, and lime absorbs gaseous matter as well as moisture, better than any of these earths taken by itself.

CHEMICAL PROPERTIES OF SOILS.

89. Soils not only sustain a plant in an erect position and afford it food, but they are the medium in which various chemical actions are gradually and constantly going on, in the preparation of different substances essential to the growth of plants.* Thus lime is constantly decomposing vegetable and animal matter in the soil, and thereby preparing food for the plant. Thus organic substances in the soil aid in absorbing ammonia and carbonic acid from the air. Thus little grains

of alkaline silicates are gradually reduced to powder, and in this state water dissolves the alkaline matter. (See Exp. 1, Art. 28.)

90. A fertile soil should not only contain all the elements essential to the growth of a plant, but they should exist in a due proportion. A deficiency of one substance, or an excess of another, may equally contribute to deteriorate the quality of the land. Hence the utility of artificial applications to land, whereby the farmer is enabled to supply what may be deficient, or in some degree to neutralize the influence of what may be in excess. The following analyses of three different soils, by Dr. Sprengel, afford a striking illustration of these remarks.

1000 parts of each soil contained as follows: —

	No. 1.	No. 2.	No. 3.
Fine earthy and organic matter, -	937	839	599
Silicious sand, - - -	45	160	400
Saline soluble matter, - -	18	1	1
	1000	1000	1000

1000 parts of the fine earthy and organic matter contained, —

	No. 1.	No. 2.	No. 3.
Organic matter, - -	97	50	40
Silica, - - - -	648	833	778
Alumina, - - -	57	51	91
Lime, - - - -	59	18	4
Magnesia, - - -	8·5	8	1
Oxide of iron, - - -	61	30	81
Oxide of manganese, - -	1	3	½
Potassa, - - -	2	trace	trace
Soda, - - - -	4	—	—
Ammonia, - - -	trace	—	—
Chlorine, - - -	2	—	—
Sulphuric acid, - - -	2	¾	—
Phosphoric acid, - -	4·5	1¾	—
Carbonic acid, - - -	40	4½	—
Loss, - - - -	14	—	4½
	1000	1000	1000

No. 1 is a highly fertile soil, which had grown corn and pulse crops *without* the application of any manure. This soil seems to contain all the essential constituents of plants. No. 2 is a fertile soil which required to be manured with gypsum. The analysis indicates a deficiency of soluble saline matter, with only traces of potassa, soda, and sulphuric and other acids. No. 3 is a barren soil; it is deficient in organic matter; potassa, soda, &c., are almost wanting; lime, oxide of iron, and silica seem to be largely in excess. In order to render this soil productive, it would require, not only to have added those substances which are absent, but some other substances which would tend to neutralize the matters in excess.

Section VIII.

IMPROVEMENT OF SOILS. MECHANICAL OPERATIONS: DRAINING, PLOUGHING, ETC. MANURING: VEGETABLE, ANIMAL, AND MINERAL MANURES. SPECIAL MANURES. ROTATION OF CROPS. FALLOWING. IRRIGATION.

IMPROVEMENT OF SOILS.

91. Land may be improved by working it, that is, by mechanical operations, such as draining, ploughing, &c.; or by improving the quality of the soil by the application of manures.

MECHANICAL MEANS OF IMPROVING LAND.

92. *Draining.* — It has already been shown (Art. 87) that damp lands are cold and unproductive. The first consideration, therefore, with the farmer in reference to such soils is to have all redundant moisture carried off by means of drains. The advantages of drainage are further shown by the following circumstances. When there is too much water in a soil, the food of the plant is either washed down to the subsoil, or it enters the roots in a very diluted state. When a soil has been drained and ploughed, it is no longer close and adhesive,

but permits the air to penetrate through it, and the roots to extend themselves in all directions. Moreover, a more healthful decomposition of the organic matter goes on in dry soils than in damp ones.

There are few soils which may not be benefited by drainage. It is especially beneficial to damp clay and peaty soils. When the soil is a clay with sand or gravel for the subsoil, it will be sufficient if the surface is drained; but when the soil is sandy, with clay for the subsoil, the drain should go down into the subsoil; otherwise the land will be damp and cold. To prevent the soil being washed away, the fall of drains should be gentle. Land should always be drained some time before ploughing. Drain pipes made of porous burnt clay, fitting into each other, are now generally adopted for agricultural purposes.

93. *Ploughing* in general, especially combined with drainage, allows water, air, and other gases to come in contact with the roots of the plants, destroys unhealthful acidity in the soil, and promotes the decomposition of vegetable matter.

94. *Subsoil* and *deep ploughing* especially bring new mineral manure, such as lime, to the surface. Agriculturists consider that the subsoil plough should not be used until after the land has been drained for one year. The reason of this must be obvious; damp soils are merely cut by the plough, whereas dry soils are broken to powder when a heavy plough passes through them.

MANURING AS A MEANS OF IMPROVING SOILS.

95. Manures are divided into three classes, viz., vegetable manures, animal manures, and mineral manures.

VEGETABLE MANURES.

96. These manures serve to open the pores of the land, and to supply organic as well as inorganic food to plants. Vegetable matter may be used as a manure either in the *green* state or in the *dry* state.

Green manures. — When green vegetable substances are put into the soil, they undergo a rapid decay, yielding a speedy supply of food to the growing plant; on the contrary, dry manures decay more slowly, but act more permanently upon the land. The cleanings of ditches, hedge sides, &c., turnip and potato tops, mixed with earth, and formed into a *compost heap*, constitute an enriching application to the soil. In some parts of this country turnip seed is sown at the close of harvest, and at the end of two months the green crop is ploughed into the land. Sea weeds form a valuable green manure.

97. *Dry manures.* — Dry vegetable substances, such as straw, sawdust, &c., decay very slowly; it is desirable, therefore, before applying such substances to the land, that they should be mixed with some matter which tends to promote fermentation. Sawdust mixed with soil and common weeds, laid up in a compost heap, and from time to time watered with the liquid manure of the farm-yard, is converted into a valuable vegetable mould. If the fermentation be not carried beyond a certain point, this compost exercises a gradual and prolonged action on the growing plants: on the contrary, if it be laid on the land when in a complete state of fermentation, the action is immediate; hence the application of the latter kind of manures to turnips and other crops which require to be brought into a condition of rapid growth. *Charcoal powder, malt dust, bran, rape dust, soot, tanner's bark*, &c., are the most common dry manures in use.

ANIMAL MANURES.

98. Animal manures are the most energetic in their action, in consequence of the nitrogen they contain, which exists in them in the form of ammoniacal salts: these salts are amongst the most powerful agents in promoting vegetation. The value of guano as an application to the soil depends chiefly on the quantity of ammonia which it contains. According to Liebig, the air immediately in contact with the soil contains small portions of ammonia, which is being continually absorbed by the

soil. The soluble portion of manures is most valuable, in consequence of the volatile substances which it contains; and hence the intelligence and industry of a farmer are shown by the care he takes of his barn yard. In warm weather the mixed manure heap, or compost heap, should be watered, and a free current of air allowed to pass over it, in order to check, in some degree, the process of fermentation, which causes the carbonate of ammonia to escape into the air. In order still further to secure the volatile matters, the heap should be covered over with a layer of soil, or, in other cases, with the sulphate of lime; these earths absorb and fix the vapors, and are thus converted into valuable applications to land. Quicklime should never be put into the compost heap, for it decomposes the salts of ammonia, and thus the most valuable portion of the manure would be dissipated into the atmosphere. As there is always a loss during fermentation, the judgment of the farmer must be exercised as to the proper time for laying the fermenting manure upon his land: this time must, in some degree, depend upon the nature of the soil and the crops to be reared. To cold soils, for example, fully fermented manure is most valuable, as it tends to warm the soil, and to stimulate the growth of the plant.

99. Boussingault gives the following analysis of an average farm yard manure:—

In 100 parts of the manure we have

Carbon,	7·41
Oxygen,	5·34
Hydrogen,	0·87
Nitrogen,	0·41
Salts and earthy substances,	6·67
Water,	79·30
	100·00

MINERAL MANURES.

100. *Lime, shell sand, and marl.* — Lime is the most important of all the mineral applications to land. It serves a mechanical purpose by giving a proper consistency to soils, and

it acts chemically by decomposing various organic substances, at the same time absorbing and fixing their gaseous products, and rendering vegetable as well as mineral substances soluble which were not so before.* Mr. Moffat, in an able paper, (published in the "Journal of the Northumberland Agricultural Society" for the year 1849,) adduces the following experiment to illustrate the mode in which lime acts on the soil: —

Experiment. — "Take some sawdust, or any fibrous matter, and boil it in water, so as to extract all its soluble matter; wash it well with cold water, and strain, so as to leave it only in a moist state; then add to it one fifth part of caustic lime, and close the mixture up in a bottle for two or three months. After this period you will find the lime to have assumed a brownish color, effervescent when vinegar is poured upon it, which indicates the presence of carbonic acid; and when water is again boiled with the mass, it will gain a fawn color, and by evaporation leave a fawn-colored powder, consisting of lime combined with vegetable extract. The sawdust, previous to the action of the lime, was perfectly insoluble in water; it is now converted into a brownish powder, which dissolves in large quantity in water. Now, this is precisely an example of the change produced by the action of lime in a caustic state upon the insoluble fibrous matters of the soil." Mr. Moffat further observes, "Caustic lime decomposes all the salts and combinations of ammonia, combining with their acids by reason of its stronger alkaline affinity, and dissipating the ammonia into the atmosphere; hence lime should never be applied with guano, nor farm yard manure, as a great portion of the nutritive quality of these manures resides in the salts of ammonia they contain."

When vegetable matter abounds in a soil, a considerable portion of lime may be used to promote the decomposition. Stiff clay lands, after draining, should be well limed; on the contrary, light lands, where there is neither much moisture nor vegetable matter, do not require such a quantity. Striking effects are produced by a due application of lime to pasture and arable lands.

* Insoluble compounds of silica and potassa exist in many of our rocks: now, when these earths are crushed and mixed with lime and water, it has been found that, after a certain time, the silica and potassa are converted into a soluble form. No doubt these changes take place, to a limited extent, in the soil.

The effects of lime gradually disappear, and after a few years the land returns to its original state, unless fresh lime be added.

Lime is removed from the soil, — first, by sinking through the loose soil; secondly, by rains which wash it away; and thirdly, by the crops carrying off certain portions of lime in the form of the carbonate.

Marl and shell sand, besides other fertilizing matters, contain a large quantity of carbonate of lime; their action upon land is similar to that of *mild* lime. Sulphuret of iron (iron pyrites) is found in some soils. This insoluble substance has no chemical action; but when it has been for a length of time exposed to the action of the air, it absorbs oxygen, and is converted into sulphate of iron, (green vitriol,) which is highly soluble, and injurious to plants. Now, the addition of carbonate of lime decomposes this salt, forming sulphate of lime and the inert oxide of iron, with the escape of carbonic acid gas.

Sulphate of lime may be used with advantage for all kinds of crops; but it is especially applicable to clover, pea, and bean crops. The sulphates generally supply sulphur to plants.

Sulphate of magnesia, as a top dressing, has been applied with great benefit to young wheat.

Sulphate of soda (Glauber salts) has been beneficially used for turnip crops; and, mixed with nitrate of soda, it has given abundant crops of potatoes.

Chloride of sodium (common salt) has generally a fertilizing influence on high or sheltered lands situated at a distance from the sea.

Kelp (the ash of sea weeds) and *wood ash* are well known to have a beneficial action on all kinds of soils.

Chloride of potassium (the residue of the nitre refiners) is sometimes used as a dressing for grass land.

Nitrates of potassa and soda. — These have been found especially beneficial to young plants. The nitric acid which they contain supplies nitrogen to the vegetable, and the potassa and soda are equally fertilizing; applied at the rate of

about 1 cwt. per acre, they promote the growth of young corn and grass.

Gas liquor contains a large quantity of ammonia; it therefore forms, when diluted with five or six times its weight of water, a superior manure for grass lands or crops generally. Sulphuric acid, or gypsum, is sometimes added, to fix the ammonia in the gas liquor.

101. *Special manures.* — As plants differ in their composition, so different plants evince a predilection for different kinds of food. Ammonia, nitrate of soda, and lime promote the growth of all plants. Lime, especially in well-drained soils, tends to bring the fruit or seeds of plants to perfection, and thus to bring in an early harvest. Gypsum promotes the growth of red clover, and phosphate of magnesia has a similar effect upon potatoes; and so on to other cases.

The specific action of particular manures on the growth of certain plants is a remarkable and interesting fact. Even certain manures promote the development of particular parts of the plant; thus, for example, manganese added to the soil improves the flowers of the rose bush.

102. *Mixed saline manures.* — A mixture of lime and common salt is recommended as an excellent manure. A mixture of sulphate and nitrate of soda, as a top dressing, has been found to produce remarkable effects on the growth of potatoes; and so on to other cases. It appears that the application of mixed saline substances is calculated to produce more beneficial results than when these substances are used alone. Hence it is that guano (which contains several saline substances) is found to act so beneficially on almost every kind of crops.

ROTATION OF CROPS.

103. The composition of soils should have a relation to the kind of plants which they are intended to grow. When a particular species of plant has been grown for a length of time on a soil, that soil becomes exhausted of the inorganic matter adapted to the growth of that particular plant. Now,

different plants extract from soils different proportions of the inorganic matter contained in them. Hence a succession of crops of different vegetables may be raised upon the same soil, when two successive crops of the same vegetable could scarcely be reared. Thus barley grows well after a crop of turnips, oats after a crop of grass, wheat after crops of beans and potatoes. The following is a specimen of a six years' rotation of crops: —

1. Wheat; 2. Turnips; 3. Barley; 4. Seeds; 5. Oats; 6. Potatoes.

The following general rule should be observed in the choice of the rotation of crops, viz., *plants which require chiefly the same kind of food should not be grown in succession;* thus plants which are grown for their roots grow best after those which are grown for their seeds.

Clover adds fertility to the soil; and hence an abundant crop of corn may be obtained after a crop of clover. In this way the use of clover has, to a great extent, superseded the system of fallowing.

104. *Fallow.* — When land has been exhausted by a succession of crops, its exhausted resources are resuscitated by manuring, and allowing it to lie dormant, exposing it at the same time (by ploughing, &c.) to the action of the air and moisture.

105. *Irrigation.* — When water is allowed to remain on land, it is injurious to vegetation; but the occasional flow of water over the surface of lands, as in our irrigated meadows, carries with it various fertilizing substances.

QUESTIONS.

INTRODUCTION.—1. Into what four classes are the laws of nature divided? What do the laws of physics govern? By what terms are the four great physical truths expressed? What phenomena do *solids* exhibit? What do *liquids*? What *airs*? What *imponderables*?

MECHANICS.—5. What is mechanics? Statics? Dynamics? Hydrostatics? Hydrodynamics? Define *matter; mass; density*.

7. What is motion? When is motion uniform? When accelerated? When retarded? What is velocity? What is momentum? What is force? Different kinds of force? What is meant by ponderable and imponderable bodies? How are forces known to us?

13. How are the properties of matter divided? Which are primary properties? Which are the secondary properties? Define *extension; impenetrability*. What are compressibility and expansibility? What is divisibility? Cohesion? Elasticity? Mobility? Inertia? Gravity?

24. What is meant by the attraction of gravitation? What is the *first* law of attraction? The *second* law? Summary law? On what does the force of gravity at any place depend? How much velocity does a falling body acquire in a second of time? State the law of increase.

25. What is the centre of gravity? What is meant by the *line of direction*? How does the line of direction govern the stability of a body? What effect has the elevation of the centre of gravity above the base?

26. What is the *first* law of motion? What are the obstacles to motion? Name the *second* law of motion. What is the parallelogram of motion? What is the parallelogram of forces? Give the *third* law of motion. By what is the intensity of the action of any force estimated?

27. Give the law of descent of falling bodies. How is motion affected in a body projected vertically upwards? 28. What is a parabola? 29. Give the law of vibration of a pendulum.

30. How many and what forces are necessary to produce motion round a centre? What is centrifugal force? By what is it counteracted?

31. On what does the amount of work done by an agent depend? What is the *unit of work*, as adopted in this country? What is the law of labor in raising a body in opposition to gravity? What is the estimate of a *horse power*?

32. What is the object of machinery? Of what is work the product? Name some of the active agents of nature. What is a fundamental axiom in mechanics? What law is founded on the principle of the equality of work? To what is the advantage gained by a machine equivalent? How is the principle of virtual velocities commonly expressed?

33. Which are the simple mechanical powers? What is the lever? How many kinds? Describe each kind. 35. What is the wheel and axle? 36. Describe a windlass. 37. By what means may the motion of one wheel be transmitted to others? 39. What is a capstan? 40. Describe a *gib crane*.

41. What is a pulley? Of what kinds? Mention some of their uses. 44. What is an inclined plane? How is its advantage estimated? 45. What is a wedge? Its uses. 46. Describe a screw. How is the screw regarded? 47. Chief uses of the screw?

48. By what means may motion be communicated from one axis to another? What is a train of wheels? What is the purpose of crown, bevelled, and face wheels? Describe the rack and pinion.

STEAM ENGINE. — Use of the crank and connecting rod? Of the fly wheel? 3. Describe the sun and planet wheel. 4. What is the use of Watt's parallel motion? 5. What is an eccentric wheel? 6. The governor? 7. Describe the steam boiler. The safety valve. 9. Use of the steam gauge? 10. Use of the water gauge? 11. The water regulator? What are the respective peculiarities of the high and low pressure engine?

HYDROSTATICS AND HYDRAULICS. — 1. What is *hydrostatics?* What is *hydraulics?* 2. How do fluids differ from solids? 3. Difference between liquids and gases? 5. What is the *first* law or property of fluid bodies? Illustrate this. The *second* law? The *third?*

13. Give the *rule* for finding the amount of pressure upon the *bottom* of a vessel containing water? 14. Upon what does the pressure on the bottom of a vessel depend?

15. Show the *upward* pressure of water by an experiment. 18. Mention some fact in nature illustrating this.

19. Rule for finding the pressure on the *side* of a vessel? Illustrate.

21. What is the centre of pressure in a vessel of water?

22. What is the specific gravity of a body? What is used as the standard of comparison?

23. What determines the sinking or floating of a body?

24. What is the *first* of the laws regulating the pressure of fluids on solids immersed in them? The *second* law?

27. Describe the hydrostatic balance. Give the rule for determining the specific gravity of a *solid* body.

28. Rule for finding the specific gravity of a *liquid?*

33. Chief use of the hydrometer?

34. Why does an iron vessel float in water?

35. What is requisite in order that a body may float with stability? Illustrate this.

36. Explain what is meant by capillary attraction.

37. What is the law of attraction in capillary tubes? What is the effect of oiling the tube?

39. Explain the meaning of *endosmose* and *exosmose.*

Hydraulics. — 41. State the law of the efflux of water through an aperture in a vessel. 42. To what is the velocity proportioned? By what is this rule modified in practice? What difference in effect is produced between the use of a short pipe and a simple aperture? Explain this.

PNEUMATICS. — 1. What is pneumatics? 2. Height of the atmosphere? Why is air believed to be material?

3. Its resistance to motion?

4. Its impenetrability?

5. Evidence of its weight?

7. To what is the atmospheric pressure equivalent? 8. How much pressure on a square inch? How high a column of *mercury* will the pressure of the atmosphere sustain? Of *water?* 9. Show the utility of the atmospheric pressure on our bodies. 10. Explain the construction and use of the *barometer*. 11. Why does water continue to flow through a siphon when put in operation?

12. Explain the cause of *intermitting springs*.

14. By what is the elasticity of air increased? State the law of elasticity of the air.

15. What relation is there between the density of the air and its height above the level of the sea?

16. How are bodies affected by heat? What class of bodies are most susceptible of this action? What is the cause of wind?

19. What is the purpose of an *air pump?* Can a perfect vacuum be produced by an air pump? Why does water boil at a lower temperature on a mountain than at the sea level?

21. Describe the construction of a *common lifting pump*. To what *limit* may a column of water be raised by the ascending piston?

22. Explain the action of a *common forcing pump*.

23. Of what use is an *air chamber* in a forcing pump?

24. Advantage of a double-acting pump? 25. How is the fire engine constructed?

30. What is meant by the *diffusion of gases?* 31. Its use in nature? 32. What do you know of the liquefaction of gases?

Acoustics. — 33. How is sound conveyed to the ear? When is sound heard? Effect of quickly-repeated impulses? What constitutes a *tone?* What effects are produced when a sonorous body is struck? 34. What property is essential to a sonorous body? On what does the *pitch* of its tone depend? What constitutes a *noise?*

35. What is necessary to the transmission of sound? 36. On what does the greater conducting power of the air depend? 37. When a gun is fired, what difference of velocity is noticed between the *flash* and the *sound?* At what *rate* does sound travel? 38. Is there any *better medium* than air for transmitting sound?

39. How is sound reflected?

40. What is the cause of echoes?

41. How may sound be magnified?

44. How are winds produced? Explain the action of *land* and *sea breezes*.

45. What are the three general classes of winds? Explain the *trade winds;* the *monsoons*, the *variables;* the *sirocco* and *simoom*. 46. What velocity constitutes a *gentle breeze?* A *brisk gale?* A *high wind?* A *hurricane?* Law of increase?

47. Why does a balloon ascend?

LIGHT. — 1. Relation of light to the eye? 2. Sources of light? 3. What are non-luminous bodies? 4. Division of bodies with relation to light? What is the characteristic of each?

5. Velocity of light?

Direction of light?

6. Law of intensity of light?

7. Two remarkable laws of light? Exemplify each.

8. Describe the two theories of the *nature* of light.

9. Law of reflection?

10. Effect on light in passing from one medium to another? What is meant by the *interference* of light? The *diffraction?*

11 State the three kinds of mirrors. By what law are mirrors governed?

12. What is the general effect of concave mirrors?

13. Where is the *principal* focus of a convex mirror? Why called the *virtual* focus? What is the general effect of convex mirrors?

14. State the law in relation to the refraction of light. On what does the higher refractive power of a medium depend? What follows when a ray of light passes from one medium to another of different density? 15. What when passing through a plate of glass? 16. What when passing into and out of a prism? 18. Describe the several forms of lenses; the *parts* of a lens.

19. What is the focal distance of a double convex lens, according as the incident rays are *parallel*, *divergent*, or *convergent?* 20. Of a plano-convex lens? 22. Of a double concave lens?

23. What effect has a convex lens upon the apparent size of an object seen through it?

24. What are *diminishing* glasses?

25. Effects of spherical aberration? The remedy?

27. Remarks on the eye? Describe its various parts. What is the cause of *short-sightedness?* What of *long-sightedness?* How do we judge of the *actual size* of an object seen at a distance? How of the *distance?* What is meant by the *visual* or *optical angle?* On what does the size of the image on the retina depend?

28. What is the purpose of a microscope? How is this effect produced?

31. What is the purpose of a telescope? What two kinds are used?

40. What is a camera obscura?

41. What is a magic lantern?

42. Give a description of the stereoscope.

Phenomena of Color. — 43. Of what is a ray of solar light composed? How may this be proved? 44. By whom was solar light first decomposed? 45. What distinct properties exist in the solar spectrum? Where is the most luminous portion located? Where the most heating portion? Where the greatest chemical intensity? 46. Which are the three fundamental colors? What do you understand by a *complementary ray?*

47. On what principle does the rainbow depend?

48. How is the phenomenon termed the *mirage* accounted for?

49. What are *halos?*

50. What is double refraction, and how produced

51. Explain the polarization of light by reflection.

53. Explain the polarization of light by refraction.

Heat. — 55. Remarks on *heat?* Free or sensible heat? Temperature? Latent heat? What does the term *caloric* express? Heat and cold? To what laws is caloric subject? What is one of the most striking effects of heat?

56. Illustrate the expansion of liquids by heat. Air. Solids.

57. What are some of the sources of heat? With what is a change of volume in a body always attended?

58. Give illustrations of good and bad conductors of heat.

59. By what principle is the radiating power of surfaces regulated?

60. Effect of heat on liquids, and of cold on vapors?

What is evaporation?

What is meant by the dew point? When is the air said to be satu-

rated with moisture? When is evaporation carried on most rapidly? What causes fog, mist, dew, &c.? Upon what does the absolute quantity of moisture which the air will sustain depend?

61. Is heat or cold produced when certain substances melt? Give examples.

62. What allowance should be made in the construction of large metallic structures?

63. Explain the principle of the compensation pendulum.

64. What is a thermometer? Different kinds? Freezing temperature? Boiling temperature?

65. In what various ways is heat propagated?

66. In what manner is radiant caloric thrown off from a surface? On what does the reflecting power of substances depend? Which are the best reflectors? State the general rule of absorption. What is meant by diathermanous and athermanous bodies?

Upon what does the power of a body to transmit heat depend?

What is Leslie's law of radiant heat?

67. According to what does the propagation of heat in liquids vary?

What follows when heat is applied to the *surface* of a liquid?

At what temperature does water attain its greatest density?

68. Remark on the heat of the ocean? Why does ice always form at the surface of the water?

69. Remark on the heat of the atmosphere.

71. On what does the *rate* of conduction in bodies depend?

72. To what is the amount of free caloric in two different quantities of the *same* substance proportional? What of equal weights of *dissimilar* substances?

What is meant by the *specific heat* of a body? What relation has the density of a body to its capacity for heat? What is a *calorimeter*? What other change attends a change of volume in a body?

73. What is *fusion*? What is *vaporization*? *Evaporation*?

74. What number of degrees represents the latent heat of steam?

76. What is the *cryophorus*?

77. What is an *hygrometer*?

78. How does the air become warm? Which strata of the atmosphere are warmest, and why? What change takes place after sunset? When does the earth radiate heat most freely? When is the deposition of dew most copious? Why does the gardener cover tender plants with straw at night? What are considered as the great causes of rain? Uses of evaporation and condensation? How may the suspension of the particles of moisture in the clouds be accounted for?

ELECTRICITY.—1. What is electricity? What are some of the means for generating it?

2. What are the fundamental facts of electricity? What are *electrics*? What fact with regard to an electrified body was first made known by Newton?

3. General remarks on conductors and non-conductors? When is a body said to be insulated? What substances are most commonly used as insulators? What effect has dampness upon insulators? Which is the best insulator, and why? Which are the best conductors of electricity? Is the atmosphere a conductor or a non-conductor? In what condition is rarefied air?

4. What is an electroscope?

5. How many kinds of electricity are there? What is the law of attraction and repulsion?

6. Does electricity pass from one part of the surface of a non-conductor to another, or does it remain stationary?

What is the relative condition of the electricity of the rubber and that of the body rubbed?

8. Explain the use of the terms *positive* and *negative*.

What is the theory of *two fluids?* The terms used? Of what use is theory in this subject?

9. What is meant by *conduction?* By *induction?*

12. Name the principal parts of an electrical machine, and their uses.

15. What are the usual appendages to the electrical machine?

18. Name some facts relating to the electric spark.

19. On what does the intensity of the electric light depend?

20. What is the electric *recoil?*

23. Upon what circumstances does the intensity of the electricity transmitted by the electrophorus depend?

26. What is *disguised* electricity?

27. Use of the condenser?

28. Explain the difference between an electroscope and an electrometer.

30. Give a description of an electrical battery. How is it discharged?

31. How is the intensity of the electricity determined by a discharging electrometer?

34. Mention some of the most common physiological effects of electricity. What is meant by an electrical *shock?*

36. Mention some of the chemical effects of electricity.

37. How is the electric fluid distributed with regard to conductors? What instrument shows this? Upon what does the intensity of the electricity depend in a conductor?

38. By whom was the identity of electricity and lightning discovered? Mention their points of agreement. Describe Franklin's experiment.

39. When is atmospheric electricity generally positive? When negative? Where most intense? Its intensity in winter compared with that in summer?

What is the character of the electricity in rain drops in a north and in a south wind? Characterize the electricity of the earth and the higher regions of the atmosphere. How often does aerial electricity attain a maximum and minimum condition? Describe its progress from one extreme to the other.

40. Which are the most common electrometeors?

41. Give an account of the aurora borealis. 42. Of the waterspout.

43. By what various modes is electricity generated?

MAGNETISM. — 1. What metal is alone attracted by magnetism? What are the substances possessing the magnetic property called?

Of what two kinds are magnets? What are natural magnets? Origin of the name? What are artificial magnets? Mention the different sorts. What constitutes a magnetic battery?

Where in a bar magnet does the power chiefly reside? How are the extremities of a magnet distinguished?

What is one of the most remarkable properties of the magnet?

2. Show the reciprocal attraction between a magnet and iron. What effect is produced by interposing wood, glass, or copper between the magnet and iron? How is magnetism distributed throughout a magnetized bar? Where are the poles and the neutral point respectively situated?

3. What is the *directive* polarity of the magnetic needle?

What is the magnetic meridian? Does it coincide with the geographical meridian? What is the difference between them called? Is the declination uniform in all places?

5. State the law of magnetic attraction. How are the poles distinguished?

6. What is the effect of breaking a magnet?

7. State the theory of magnetism. Mention some of the phenomena of magnetism.

8. What is the law of the *attractive force* of the magnet?

9. What is magnetic *conduction*? What is magnetic *induction*?

12. Describe the property called the *dip of the needle*. Is the angle of the needle's dip uniform at all places on the earth?

16. What are the requisites in the quality of steel for making magnets? What is necessary in the form and dimensions of artificial magnets?

17. How may a soft iron bar be rendered magnetic?

Which is the most powerful means of rendering bodies magnetic?

18. How is the earth to be regarded in order to account for the directive and dipping properties of the needle? Which of the magnetic poles of the earth is the positive pole? What is the situation of the terrestrial magnetic poles?

What are isoclinic lines? With what do they coincide?

19. To what variations are the earth's magnetic powers subject? How indicated? Characterize the *regular* variations. Which of the secular variations has been most observed? With what are the *irregular* magnetic variations connected?

22. What is Ampère's theory of magnetism?

VOLTAIC ELECTRICITY. — 1. How is voltaic electricity produced? By whom was it first observed, and under what circumstances? How did Galvani account for it? How did Volta account for it?

2. Describe the voltaic pile. Describe the *Couronne de Tasses*, or Volta's battery.

8. What is a voltameter? What three kinds are in use?

9. What is considered as one of the most important features of voltaic electricity? What remarkable fact is connected with voltaic decomposition? How are the constituents of water disposed after decomposition? What system is based upon this fact? What is the electrical state of the elements which are attracted by the positive pole?

10. Upon what do the arts of electrotyping and electroplating depend?

12. How may decomposition be impeded or arrested by voltaic electricity?

13. Give instances of the luminous and heating effects of voltaic electricity. Upon what does the temperature to which a conducting wire will be raised by a battery depend?

Upon what does the calorific effect depend?

14. State some facts in relation to the physiological effects of voltaic electricity. Upon what do these effects seem to depend?

ELECTRO-DYNAMICS. — 1. Explain the construction of the right and left-handed helices. How should helix wires be prepared? State the facts in connection with a needle magnetized by a right-handed and a left-handed helix.

2. What is an *electro-magnet*? How long will an electro-magnet retain the magnetic property?

7. State the five general laws of electro-dynamic action.

10. State the two laws according to which electric currents act upon each other.

What are the laws respecting angular currents?

Electro-Dynamic Induction. — 12. Who first discovered the laws of electro-dynamic induction? What did he demonstrate? When does the induction of the current act?

16. What is thermo-electricity? Give examples.

18. What are *dia-magnetic* bodies?

19. Describe the electro-magnetic telegraph.

20. What are the peculiarities of Morse's telegraph? 21. Of Bain's? 22. Of House's?

CHEMISTRY. — 1. Of what does the science of chemistry treat? How many elementary substances are there? Difference between a simple and a compound substance? 2. How are the elementary substances divided? Name those of each class.

4. Mention the various kinds of attraction.

9. How does chemical affinity differ from all other kinds of attraction? By what are all chemical changes produced? When does combination take place? When decomposition?

10. Is any thing in nature ever destroyed or annihilated?

11. Characterize *acids*. *Alkalies*.

12. What is a solution? How is the process of solution accelerated?

13. How is carbon obtained? What is the product of the combustion of charcoal? Characterize *carbonic acid gas*.

14. Describe hydrogen. Where found? Characterize *hydrogen*.

15. Composition of the atmosphere? What takes place in the process of breathing? Characterize *oxygen*. Characterize *nitrogen*. Relation of oxygen to plants and animals?

16. What is ammonia? Where found?

17. What is nitric acid?

18. Give a description of the atmosphere. What are its constituents?

19. Where is native sulphur obtained? With what metals is it found in combination? Which is the most important compound of sulphur?

20. Characterize phosphorus.

21. Characterize iodine. From what is it obtained? Chief use?

22. Characterize chlorine. Use of chlorate of potassa?

23. Characterize hydrochloric acid.

24. From what are potassa and soda formed? Why called *fixed* alkalies? In what does potassa largely exist?

25. In what various forms does lime exist? Its relation to soils? Its uses in agriculture? What is the metallic base of lime?

26. Characterize magnesia.

27. Characterize alumina.

Of what is pure clay composed?

28. Characterize silica. What is its base?

29. In what forms does iron exist in nature?

30. In what states does *copper* exist in nature?

31. Common native form of *lead*?

32. Most common salt of *chrome*?

33. In what state is *mercury* found?

34. Remark on *zinc*.

35. Characterize *silver*. 36. *Gold*. 37. Platinum.

38. What is the doctrine of chemical equivalents? Give examples.

40. What is taken as the symbol of a simple substance? What does the name of a compound indicate? Examples?

65. Of what does the *organic* part of plants consist? Of what the *inorganic?* Is their proportion uniform?

66. Effects of different kinds of plants upon the inorganic matter of soils? State facts in illustration of this.

67. What shows the necessity for manuring soils?

68. Which are the most abundant compound organic substances in plants? Their constituents? By what circumstances are most vegetable compounds characterized? What are these distinct compounds called?

69. What is a singular fact with regard to lignine, starch, gum, and sugar?

What is *catalysis?*

70. What does *fermentation* signify? What is the result of the fermentation of *saccharine* matter?

71. What is *acetous* fermentation? What purpose does yeast serve in fermentation?

72. Which are the most common vegetable acids?

73. Give an account of the process of germination.

74. Which parts of a plant are essential to its growth? Describe the *trunk*, or stem. The *root*. The *leaf*. In what other way does a plant receive carbonic acid?

75. What must the food of plants contain? What substances afford this food? Effects of light and heat upon plants?

76. Composition of soils? Whence is the organic part derived? What is *humus?*

77. Of what does the inorganic part of soils consist? Characterize the *saline soluble substances;* also, the *earthy insoluble substances*.

78. What constitutes a *sandy* soil? A *loamy* soil? 80. What *marl? Calcareous* soil?

83. Origin of soils?

84. State some of the *mechanical* properties of soils. 85. Effects of heat on clay and peat? 86. Of what advantage is the absorbent power of clay? 87. Necessity for warmth.

89. State facts with reference to the chemical properties of soils.

90. Importance of a *due proportion* of the essential elements of a fertile soil?

91. How may land be improved?

92. Remark on *draining?* 93. On *ploughing?* 94. On *subsoil* and *deep ploughing?*

95. Name the three classes of manures. 96. What are the purposes of *vegetable* manures? Remarks on *green* manures? On *dry* manures?

98. Characterize *animal* manures. What is the important constituent of *guano?* Which portion of manures is most valuable? Why?

100. Most important of *mineral* manures? Mention some of its uses. What other minerals are used as manures?

101. Give instances of the use of *special* manures. 102. Advantages of mixed saline manures?

103. Relation between the soil and the plant to grow from it? Effect of growing a particular species of plant on a soil? Effect of a succession of crops? Example? Rule?

104. What is meant by *fallowing?*

105. Remark on irrigation?